DIETS AND PREY SELECTION OF PINFISH AND SOUTHERN FLOUNDER IN A *HALODULE WRIGHTII* SEAGRASS MEADOW

A Dissertation

by

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ABSTRACT

Diets and Prey Selection of Pinfish and Southern Flounder in a *Halodule wrightii* Seagrass Meadow. (August 1991)

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Effects of prey species and densities on diet and selection by pinfish and southern flounder were investigated in a *Halodule wrightii* seagrass meadow. A drop sampler/rotenone collection procedure was used to quantitatively sample predator and prey densities during the spring and early summer. Densities of most infauna, epifauna and macrofauna prey peaked in April and May. Periods of low density were attributed to mortality from environmental extremes and predation. Overall, pinfish were much more abundant than southern flounder, and densities of pinfish declined over the sampling period.

The plant component in the diet of pinfish increased as these fish grew through the spring and early summer. Rather than evidence for a switch in this animal's diet, however, this shift to a predominantly plant diet appeared to be due to low densities of preferred animal prey. Plant material may have been incidental in the diet of these fish. Among animal prey, a modified linear index (MLI) was used to detect selection of prey over random feeding. Pinfish positively selected amphipods as prey and avoided annelids. Shrimp prey had positive MLIs in late spring and early summer, but values were not significantly different from those of random feeding.

Data from fish collected in the field indicated that pinfish consumed prey between 10 and 33 % of their own total length. Both predators exhibited no strong selection among available sizes in laboratory experiments. When two species of shrimp of the same size were offered to pinfish and southern flounder, predator fish did not significantly select either prey.

In field experiments where prey densities were manipulated, pinfish selected amphipods and brown shrimp when they were available at elevated densities. Grass shrimp were negatively selected by pinfish even in treatments with increased densities of these shrimp. Southern flounder selected brown shrimp as prey regardless of their densities, while avoiding grass shrimp and amphipods.

DEDICATION

I dedicate this work to the three most important ladies in my life:

my mother, my wife and my daughter.

ACKNOWLEDGEMENTS

I acknowledge the support given to me by my committee members who endured this project's slow development and completion. I especially thank Dr. Thomas Minello whose tutelage has made most of this work possible. I thank Dr. Taisoo Park for considering my future interests and always understanding my needs of financial support. I thank Drs. Dave Aldrich, Sammy Ray and Merrill Sweet for the invaluable lessons they taught me.

I thank National Marine Fisheries Service, Galveston Laboratory and personnel for financial support, a place to work and loan of equipment in portions of this project. I thank those who assisted with sorting of some of the core samples: Alisha Goldberg, Janet Martinez, Terry McTigue, and Ron Wooten. I appreciate the sometimes unknowing support provided by Mark Pattillo and Dr. Roger Zimmerman. I would like to acknowledge the financial support provided by Texas A&M University and Texas A&M University at Galveston.

A special note of gratitude to three great friends. Colleagues, Mark Benfield and Eduardo Martinez, who tolerated my verbal abuse, but would listen to the good ideas as well, and provided essential computer assistance. Also, Dr. Michael Evans provided many incentives, my only regret was that he was not more involved.

I am especially indebted to my wife, Gretchen. This has been a long haul and you patiently awaited the completion of this portion of our lives. Your support and thoughtfulness has made most of this possible, thank you.

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INTRODUCTION

Predators influence the ecological structure of many communities, and in freshwater systems, fish predation has been shown to be necessary in the maintenance of community assemblages (Brooks and Dodson 1965; Zaret 1980; Kerfoot and Sih 1987; Northcote 1987). Many predator-prey studies, in estuarine systems, have centered around the protective function of seagrass meadows (Virnstein 1977; Weinstein and Heck 1979; Stoner 1980; Heck and Thoman 1981; Huh and Kitting 1985; Jensen and Jensen 1985; Rozas and Odum 1987, 1988; Ryer 1988) and salt marshes (Minello and Zimmerman 1983; Minello and Zimmerman 1985; McIvor and Odum 1988; Minello *et al.* 1989b; Thomas 1989), where density and structure of macrophytes reduce predation rates on a wide variety of prey species. Species assemblages in estuaries are diverse and include endemic prey and predators and also transient juveniles of commercially and recreationally important fishery species, such as penaeid shrimp. In contrast to stable freshwater systems, the appearance of transient recruits in estuarine habitats can rapidly shift the relative abundance of prey species available to predators. The overall objective of this research study was to describe the variability in prey species assemblages in an estuarine seagrass bed and determine effects of prey density on predatory fish diets and prey selection.

The two predators examined in this study have contrasting forage behaviors and abundance patterns. The pinfish, *Lagodon rhomboides*, is a chase and/or group-type predator that is ubiquitous and abundant in the estuaries of the Gulf of Mexico. Depending on size of the prey, pinfish will either take its prey whole or, in pieces (Darcy 1985; Luczkovich 1988). The southern flounder, *Paralichthys lethostigma*, is a solitary ambush-type predator and, although considered common, this predator is far less abundant than pinfish [usually 1 to 2 orders of magnitude (Rice *et al.* 1988)]. Southern flounder typically engulf their prey whole with a sudden

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Style and format follow Ecology.

opening of the buccal cavity creating a vacuum which sucks up the prey (Olla *et al.* 1972).

Stomach analyses on fishes in the northern Gulf of Mexico have been used to identify important prey (Reid 1954; Diener *et al.* 1974; Carr and Adams 1973). These studies have shown that pinfish are omnivorous and consume annelids, molluscs, crustaceans and plant material. Young pinfish feed on small crustaceans and fish, then change to an herbivorous diet as they grow (Stoner 1980). Brown shrimp have been indicated as important components in the diets of juvenile estuarine fishes (Minello and Zimmerman 1983; 1985; Minello *et al.* 1989a; 1989b), but few studies have examined prey selection.

Prey species examined in this study were determined from results of stomach analyses in other studies and from abundance estimates and availability in the seagrass habitat. The resident prey species examined were amphipods and the grass shrimp, *Palaemonetes pugio*. The postlarval stage of the common commercial brown shrimp, *Penaeus aztecus*, a transient species, was also examined. Brown shrimp usually arrive in waves from the nearshore coastal waters in the early spring. The effect of this influx of previously unavailable prey into the seagrass meadow on predator-prey interactions was of special interest. Although little is known of postlarval brown shrimp mortality rates, Minello *et al.* (1989b) suggested that predation by fishes was the major cause of mortality in estuarine nurseries.

Specifically, the objectives of this study are: 1) to measure predator and prey abundances and determine whether changing prey densities in the environment would be reflected in the diet of the predators; 2) to identify prey consumed through stomach analyses; and 3) to determine the driving forces controlling prey selection by examining effects of prey size and density through laboratory and field experiments. Essentially, only a short period of 4-5 months exists during the spring for these interactions to occur when prey and predators of the appropriate densities and size coincide in the seagrass habitat.

The study area was a *Halodule wrightii* seagrass bed in Christmas Bay of the Galveston Bay system. This study is presented in four chapters. Chapter one is a description of prey and predator size and density in the seagrass bed throughout the spring of 1986. Chapter two is a presentation of the diet of pinfish and southern flounder in relation to the prey density surrounding the predator at the time of capture. Chapter three includes results from laboratory experiments conducted to determine effects of size and species on prey selection. Finally, chapter four is a discussion of field experiments conducted to examine the effect of changing prey density on predator diet.

CHAPTER I

PREDATOR AND PREY DENSITIES DURING THE SPRING AND EARLY SUMMER MONTHS FROM A SEAGRASS MEADOW IN CHRISTMAS BAY, TEXAS

INTRODUCTION

Seagrass meadows in the southeastern United States are some of the most productive estuarine habitats and support large numbers of estuarine animals. The infauna, epifauna and macrofauna provide abundant food resources for larger organisms. Greater numbers of these prey organisms occur in seagrass than other estuarine habitats, such as algae (Nagle 1968; Gore *et al.* 1981; Leber 1985), *Spartina* (Thomas *et al.* 1990; Zimmerman *et al.* 1990), and nonvegetated substrates (Young and Young 1982; Virnstein *et al.* 1983; Stoner and Lewis 1985). Differences in animal abundances also occur among different species of seagrass. Turtlegrass (*Thalassia testudinum*) meadows generally have the highest concentrations of animals in comparison with other seagrass meadows. These differences may be related to location within the estuary or differences among tropic, subtropic and temperate regions (Weinstein and Heck 1983; Virnstein *et al.* 1984; Heck and Wilson 1987). Within one location, however, higher densities of polychaete annelids (Santos and Simon 1974) and epifaunal crustaceans (Huh and Kitting 1985) have been found in turtlegrass than in nearby shoalgrass (*Halodule wrightii*) meadows.

Halodule wrightii is considered a pioneer species in terms of ecological succession of seagrass and often occurs on the fringe of other seagrass meadows (Zieman 1982). This species is more tolerant to environmental extremes of salinity, temperature, turbidity and exposure (McMillan and Moseley 1967; McMahan 1968). The *H. wrightii* seagrass meadow located in Christmas Bay, Texas experiences these variable environmental conditions. This seagrass bed is an important habitat for local fish and decapod crustaceans (McEachron *et al.* 1977). Abundances of invertebrates and fishes were found to be higher in this seagrass meadow than in other submerged aquatic macrophytes, intertidal marsh or nonvegetated habitats throughout the Galveston Bay complex (Thomas *et al.* 1990; Zimmerman *et al.* 1990). Shrimp populations, however, were lower in the *H. wrightii* meadow of Christmas Bay than other seagrass meadows further south in Texas (Penn 1979).

Quantitative sampling in seagrass is often difficult, and a variety of techniques have been employed to estimate animal density and relative abundance. The techniques and sampling gear used are usually dependent on the fauna of interest, and some techniques are more quantitative than others. Cores and sieves are normally used to assess infauna and epifauna populations, although core diameter has been shown to affect abundance estimates (Lewis and Stoner 1983; Huh and Kitting 1985). Otter trawls and various push or pull frame trawls are commonly used for examining fish and decapod crustacean populations. These methods underestimate populations because many mobile species can avoid trawls (Zieman and Zieman 1989). When the trawl mesh becomes clogged with seagrass, a wave is created in front of the trawl, pushing animals away. In addition, seagrass prevents the trawl from reaching the substrate allowing escape below the lead line. Both clogging and escaping to the substrate result in avoidance of the net by mobile species. To provide better estimates of small fish and macrocrustacean densities in seagrass, drop nets and throw cages have been developed (Adams 1976a, 1976b; Gore *et al.* 1981; Huh and Kitting 1985). These devices descend through the water column and surround a fixed area with a mesh wall. Pop nets are similar but the walls ascend from the bottom, and they have been commonly used in freshwater submerged aquatic macrophyte habitats (Larson *et al.* 1986; Serafy *et al.* 1988; Killgore *et al.* 1989). Animals enclosed in these devices are collected with seines and dip nets; however, highly mobile and burrowed animals may escape capture. For shallow-water habitats (< 1 m), a drop sampler which encloses an area with solid walls was developed by Zimmerman *et al.* (1984). The water is removed by a pump and passed through a net. Recovery of enclosed animals was over 90 % by this technique, and density estimates were much higher in comparison to seines and trawls.

The objective of this part of my study was to determine faunal densities within the *H. wrightii* seagrass meadow in Christmas Bay during the spring and early summer. Animals were collected using a modified drop sampling technique in which rotenone was used to force burrowed animals out of the sediments. This sampling effort was mainly designed to track density and size of two predators (pinfish and southern flounder) and three prey groups (amphipods, *Palaemonetes pugio* and postlarval *Penaeus aztecus*). During the spring, densities of these prey increase through reproduction and recruitment and decrease as they are eaten by predatory fish.

MATERIALS AND METHODS

Field Sampling

Twelve replicate samples of macrofauna were collected every two weeks from February through July 1986 to determine species density and variability. The sampling area of the seagrass bed was approximately 125 x 525 m (6.5 ha) (Figure 1.01). Within the area, sample locations were randomly chosen from an imaginary 10 x 20 grid which was aligned with two fixed positions. Small patches of turtlegrass were present in the seagrass meadow, and an *a priori* decision was made to replace a replicate if it contained turtle grass.

The fiberglass drop sampler used to collect macrofauna enclosed an area 1.48 m long and 0.57 m wide (0.84 m^2). The sampler had no bottom and was 1.14 m high. The sampler was held by hand and released from the side of a drifting skiff. Once in place, temperature, salinity and dissolved oxygen were measured within the sampler. Salinity was measured at the surface with an American Optical Refractometer. Temperature and dissolved oxygen were measured near the bottom with a YSI Model 57 Oxygen Meter. Average water depth was determined from three measurements along the length of the sampler. A water sample was taken and used to measure turbidity in the laboratory with an HF Instruments DRT-15 turbidimeter (calibrated with a Formazin standard). Turbidity was recorded as Formazin Turbidity Units (FTUs). Light levels were measured in the air at the surface and at 2 cm above the bottom for each replicate with a

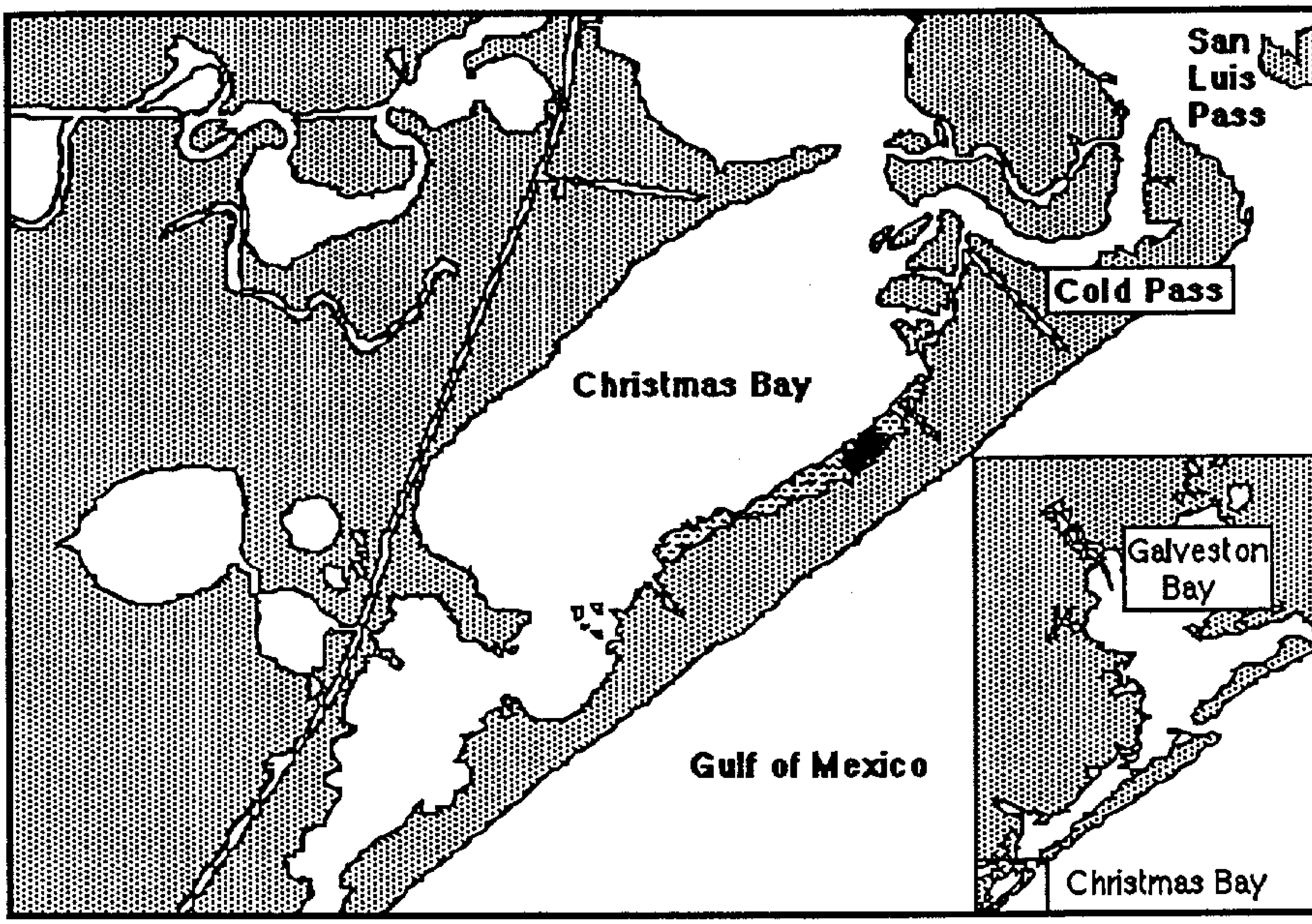

Figure 1.01. Map depicting sampling site in Christmas Bay, Texas. Location of sampling site (black area) and seagrass (stippled area) in Christmas Bay. Insert shows Christmas Bay in relation to Galveston Bay and the Gulf of Mexico. Water movements and migration routes of transient species to and from the Gulf of Mexico are via San Luis and Cold Passes.

Licor LI-188b meter equipped with an LI-192SB underwater cosine sensor. This sensor measures electromagnetic radiation in the visible wavelength spectrum of 400 to 700 nm; light energy is expressed in microeinsteins ($\mu E\ s^{-1}\ m^{-2}$).

A Hydrolab® Datasonde was also used to record temperature, salinity, and dissolved oxygen every 30 minutes for periods of approximately two weeks in duration throughout the study. The data were not continuous because the equipment was periodically removed for downloading and recalibrating. The unit was stationed near the center of the sampling area within the seagrass bed at about 10 cm above the bottom.

A 10-cm diameter core sample (78.5 cm^2) was also taken within each drop sample to determine the density of amphipods and other potential benthic prey, as well as density of the seagrass. The top 5 cm of the core was sieved through a 0.25 mm^2 mesh, placed in a labelled plastic-lock bag and preserved with 10 % formalin-Rose Bengal-seawater solution for sorting in the laboratory.

Benthic macrofauna and nekton were collected using a 5 % NoxFish® (rotenone) solution which was added to the water within the sampler to achieve a concentration of 5 ppm. The sample was allowed to set to let the rotenone drive animals from shallow burrows and kill them. After twenty minutes, macrofauna were dipped out using both a hand net and a frame-net with 0.5 mm^2 mesh. The frame-net fit snugly along sides and bottom of the sampler and was moved from one end of the sampler to the other sweeping the entire water column. Sweeps were continued until three sweeps in a row were void of any macrofauna. Each macrofauna sample was placed in a labeled, plastic-lock bag and stored in a 10% formalin-Rose Bengal-seawater solution until sorting at the laboratory.

Recovery efficiency of this sampling method was determined with grass shrimp. Thirty grass shrimp (14-24 mm TL), marked by clipping a portion of a uropod, were placed into a sampler already positioned in the seagrass. After acclimating for twenty minutes to the sampler conditions, rotenone was applied and macrofauna were collected as described above. Average recovery of the tagged grass shrimp was greater than 95% (Table 1.01).

Table 1.01. Results of recovery efficiency of tagged grass shrimp from the 0.84 m^2 sampler using the rotenone and dip netting procedure to collect macrofauna.

Rep	Number of Tagged Grass Shrimp	Size Range (mm TL)	Number of Recovered Tagged Grass Shrimp	Grass Shrimp Not Tagged	Percent Recovered	Depth (cm)
1	30	16-24	28	61	93.33	24
2	30	15-23	28	22	93.33	23
3	30	14-21	29	24	96.67	30
4	31	16-23	31	29	100.00	28
Mean	30.25		29.00	34.00	95.83	26.25
Std Dev	0.50		1.41	18.24	3.19	3.30

Laboratory Analysis

Animals were sorted, removed and identified from core samples using a Wilde dissecting microscope at 50 x magnification. Animals were initially categorized into the following taxa: platyhelminths, annelids, nematodes, bivalves, gastropods, ascidians and crustaceans. The crustacean group was further identified to the order level; and, within the amphipods, five species of interest were measured to the nearest millimeter for total length (from front of cephalon to tip of telson). Live seagrass was separated into species (*Halodule wrightii* and *Halophila engelmanii*), and above ground turions and leaves were each counted. The above ground (leaves and turions), below ground (stolons and rhizomes) and detritus (consisting of loose leaves, unidentified plant material and animal tubes) components were dried at 60-70 °C for 24 h and weighed to the nearest 0.1 mg.

The macrofauna samples were sorted and identified to the lowest possible taxon. Caridean and penaeid shrimp were measured for total length (tip of rostrum to tip of telson) to the nearest millimeter. Measurements of crab carapace widths were also recorded to the nearest millimeter. Pinfish and southern flounder were measured for total length (tip of snout to tip of tail) to the nearest millimeter. Other fish species collected were identified, but not always measured.

Data were entered into Microsoft® Excel spreadsheets and statistical analysis conducted with PC SAS. Mean and standard error of species sizes were calculated for each sample date based on the means of individuals within each sample.

RESULTS

Abiotic Parameters

Temperature, salinity and dissolved oxygen trends were typical for the spring and early summer seasonal period for this study area. Mean water temperature increased over the spring; extremes ranged from 6.8 °C in February to 35.1 °C in July as recorded by the datasonde (Figure 1.02). The mean water temperature in the drop samples ranged between 16.3 °C in

March and 31.8 °C in July. Mean temperatures of the drop samples were slightly higher than datasonde means because they were measured during the day. Salinities were relatively stable within the drop samples with an overall mean and standard error of 28.1 ± 2.8 ‰; mean salinities for sample dates ranged from 23.1 to 32.2 ‰ (Figure 1.03). High variability in salinity of the samples on two dates (19 March and 31 May) was caused by rainfall. The datasonde salinity record had more variability than salinity measured within the drop samples; mean datasonde salinities ranged between 10.6 in July to 32.2 in March. Daily ranges of dissolved oxygen were relatively low until the warmer summer months when dissolved oxygen was highly variable over the day with ranges often exceeding 15 ppm (Figure 1.04). Daily mean dissolved oxygen reached a minimal value on 19 July of 0.53 ppm. The lowest mean dissolved oxygen within the drop samples was 5.07 on 30 April. Mean dissolved oxygen in the sampler coincided with daily means recorded by the datasonde.

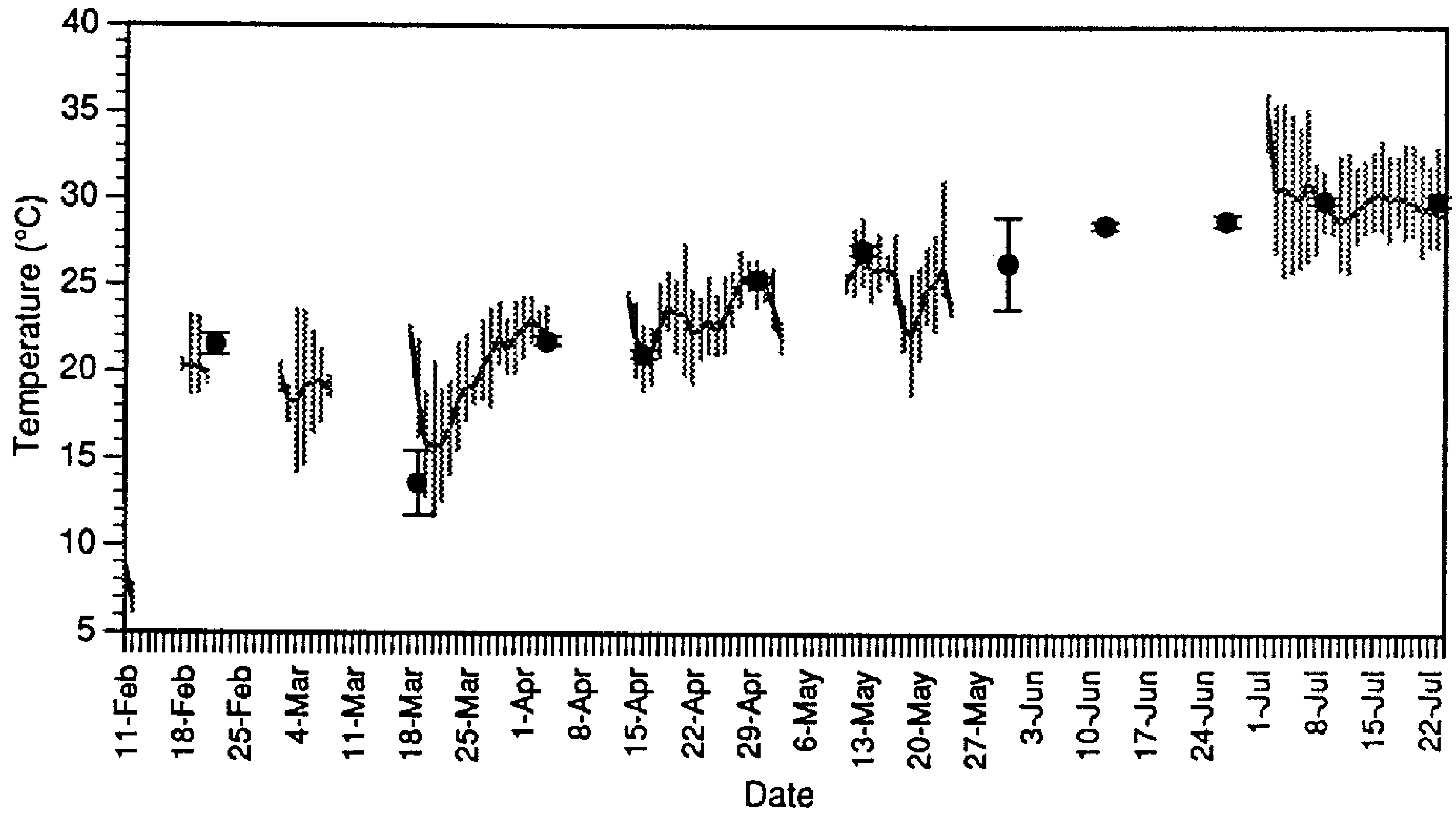

Figure 1.02. Temperature records from the datasonde, depicting mean (line) and range (vertical dotted lines), and within the drop samplers on each sampling date, mean (●) ± 1 standard error (vertical solid line).

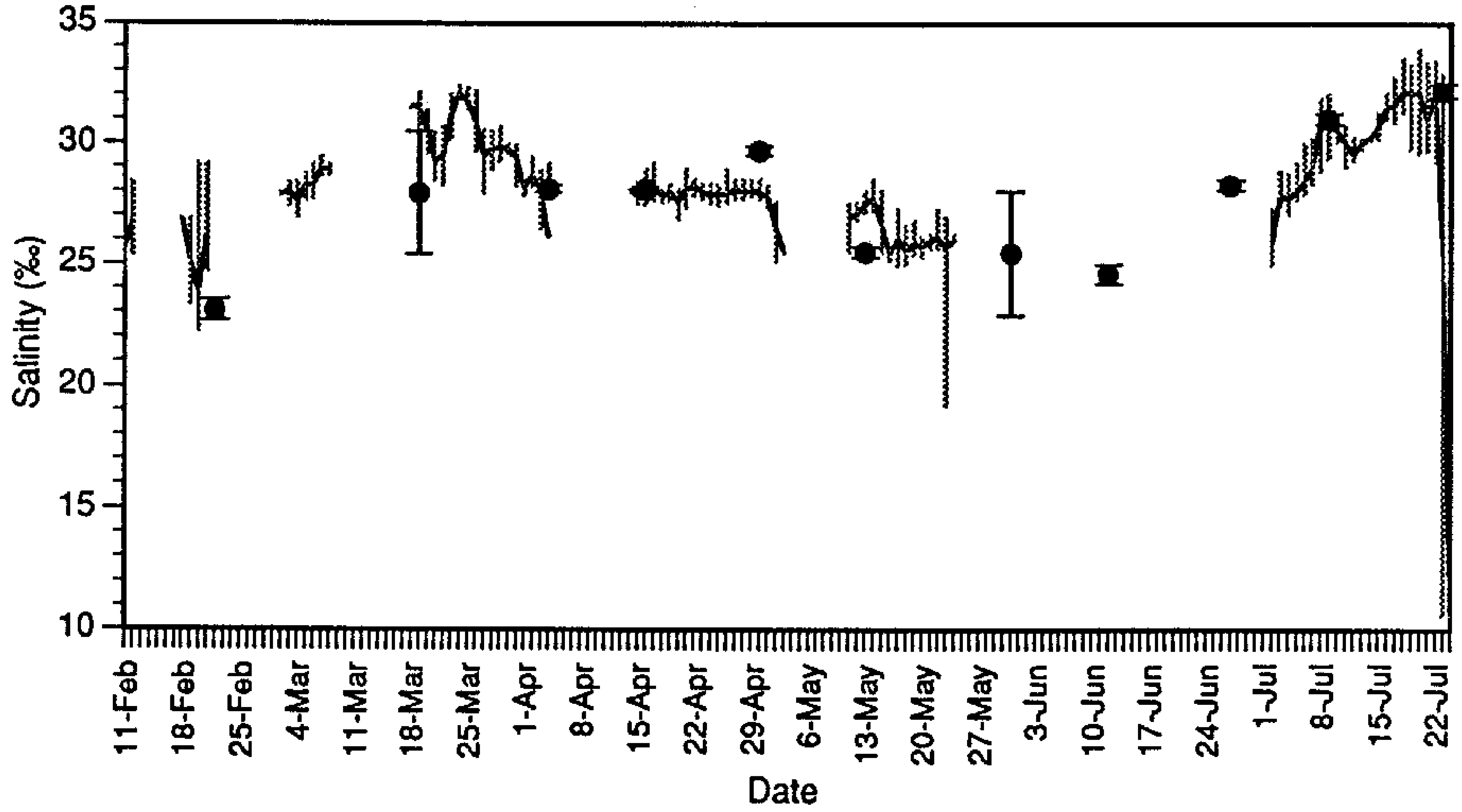

Figure 1.03. Salinity records from the datasonde, depicting mean (line) and range (vertical dotted line), and within the drop samplers on each sampling date, mean (●) ± 1 standard error (vertical solid line).

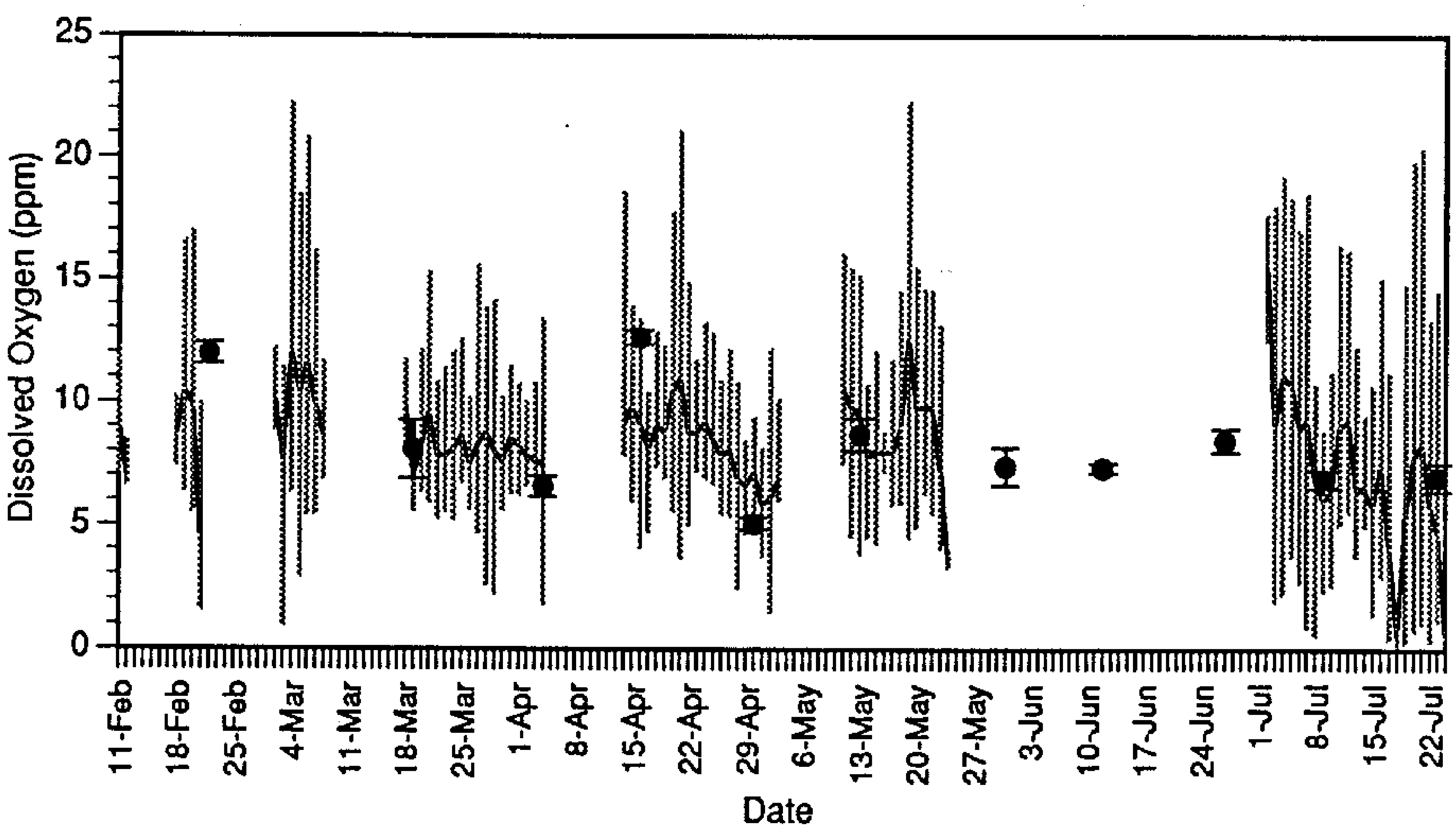

Figure 1.04. Dissolved oxygen records from the datasonde, depicting mean (line) and range (vertical dotted line), and within the drop samplers on each sampling date, mean (●) ± 1 standard error (vertical solid line).

Sampling times were scheduled to occur during the day regardless of tidal events. Daily tidal range is around 30 cm, and wind is usually important in controlling water depth in Christmas Bay. Most samples were collected at or above 50 cm depth (Figure 1.05); the shallowest depth for any sample encountered was 24 cm and the deepest sample was 80 cm.

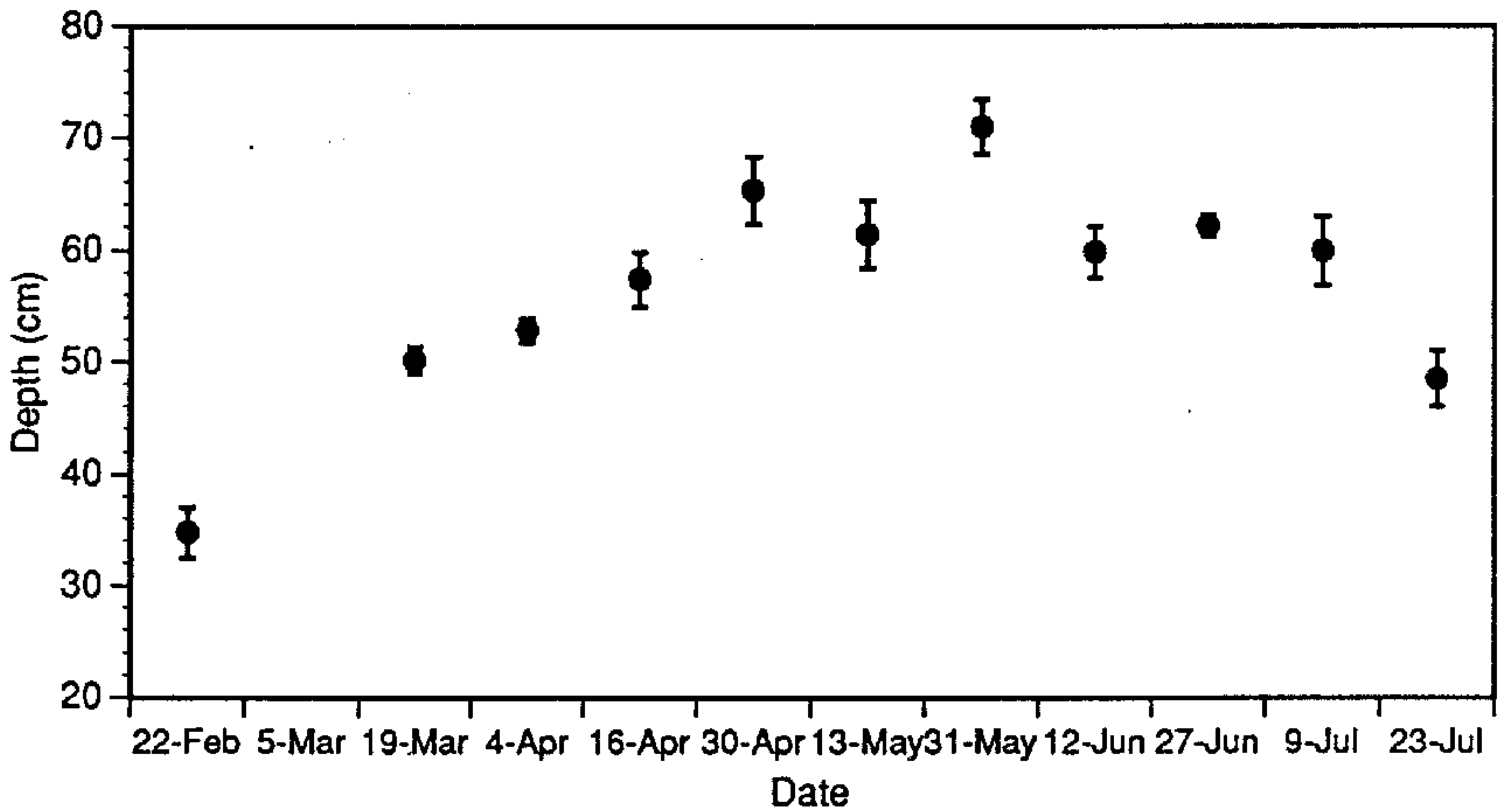

Figure 1.05. Mean ± 1 standard error of depth recorded for each sampling date.

Turbidities were not measured on the first three sampling dates but a general decline in turbidity occurred during the spring (Figure 1.06). Different direction of prevailing winds and reduced wind speeds during the summer may be responsible for reduced turbidity in the summer. Turbidities corresponded well with other records taken from Christmas Bay during the spring (Spring 1985 unpublished data, NMFS, Galveston Laboratory).

Mean light at the surface generally increased from February to July, although cloud cover caused daily variations (Figure 1.07). Light at the bottom was reduced and relatively stable. Bottom light did not show the same trend as the surface. Highest values of bottom light were recorded in early spring and in summer months. Turbidity and depth affect bottom light and both of these factors were high in April and May.

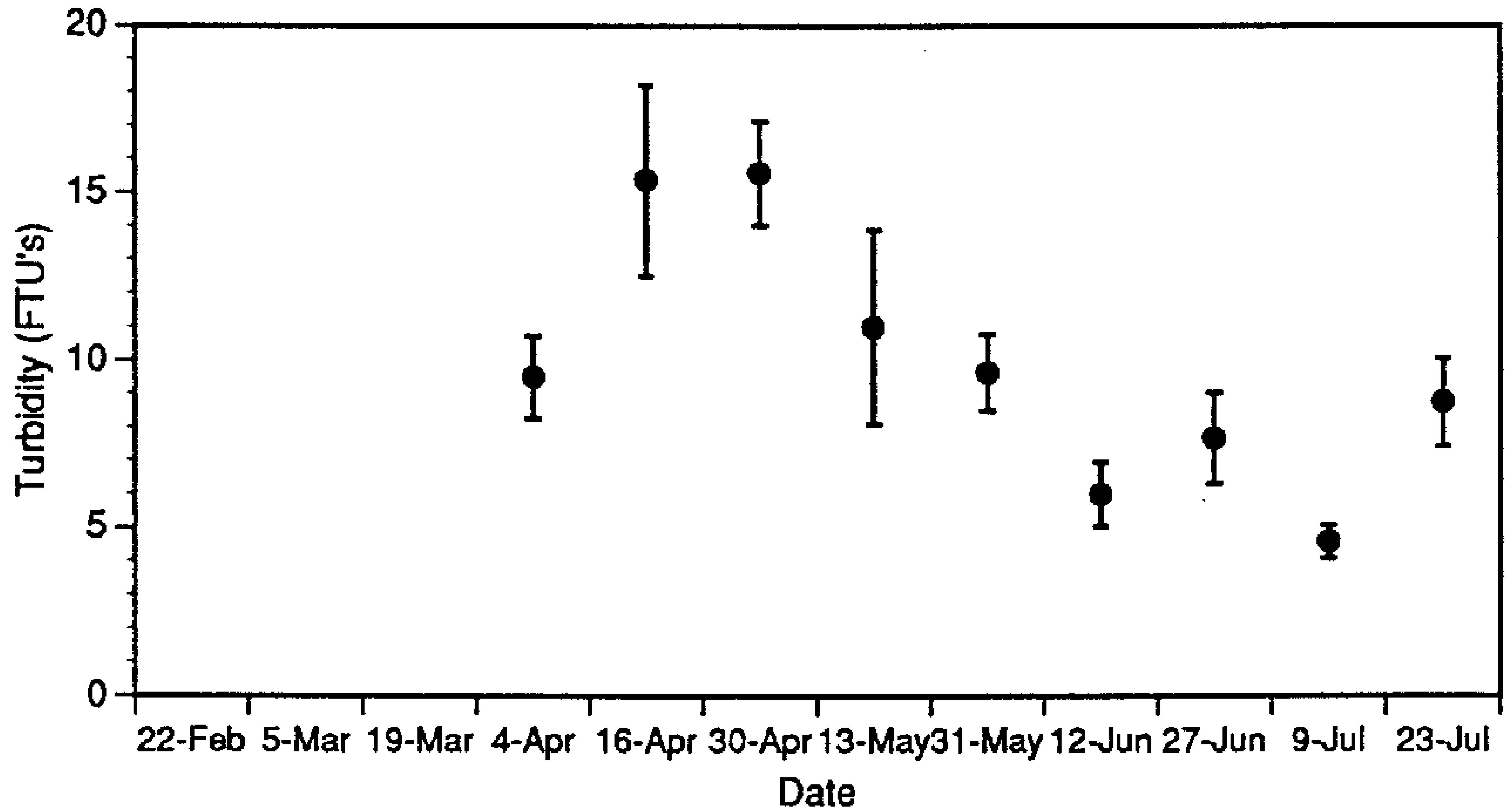

Figure 1.06. Mean ± 1 standard error of turbidities recorded for each sampling date.

Biotic Parameters

Seagrass Leaf and shoot counts of *Halodule wrightii* were high in early spring (Figure 1.08), and biomass was relatively low. The highest densities of shoots and leaves occurred during the first three sampling dates. Densities were lowest on 16 April and then increased and remained stable at around 70 to 80 leaves per core. Above ground biomass ranged from a low of 65.1 on 16 April to 189.3 mg dry weight/core on 31 May. Above ground biomass generally increased until May and then declined and stabilized from early June to July. Percentages of below ground biomass to total biomass ranged from 65 to 86 %.

Halophila engelmanii was interspersed with *H. wrightii*, but was sparsely distributed. Blades and shoots of *H. engelmanii* increased from February to May and then declined from May to July (Figure 1.09). The above ground biomass peaked in April and declined from May to July. Low above ground biomass in February was due to small, emerging leaves, while in July, low above ground biomass was attributed to leaves that had been bitten.

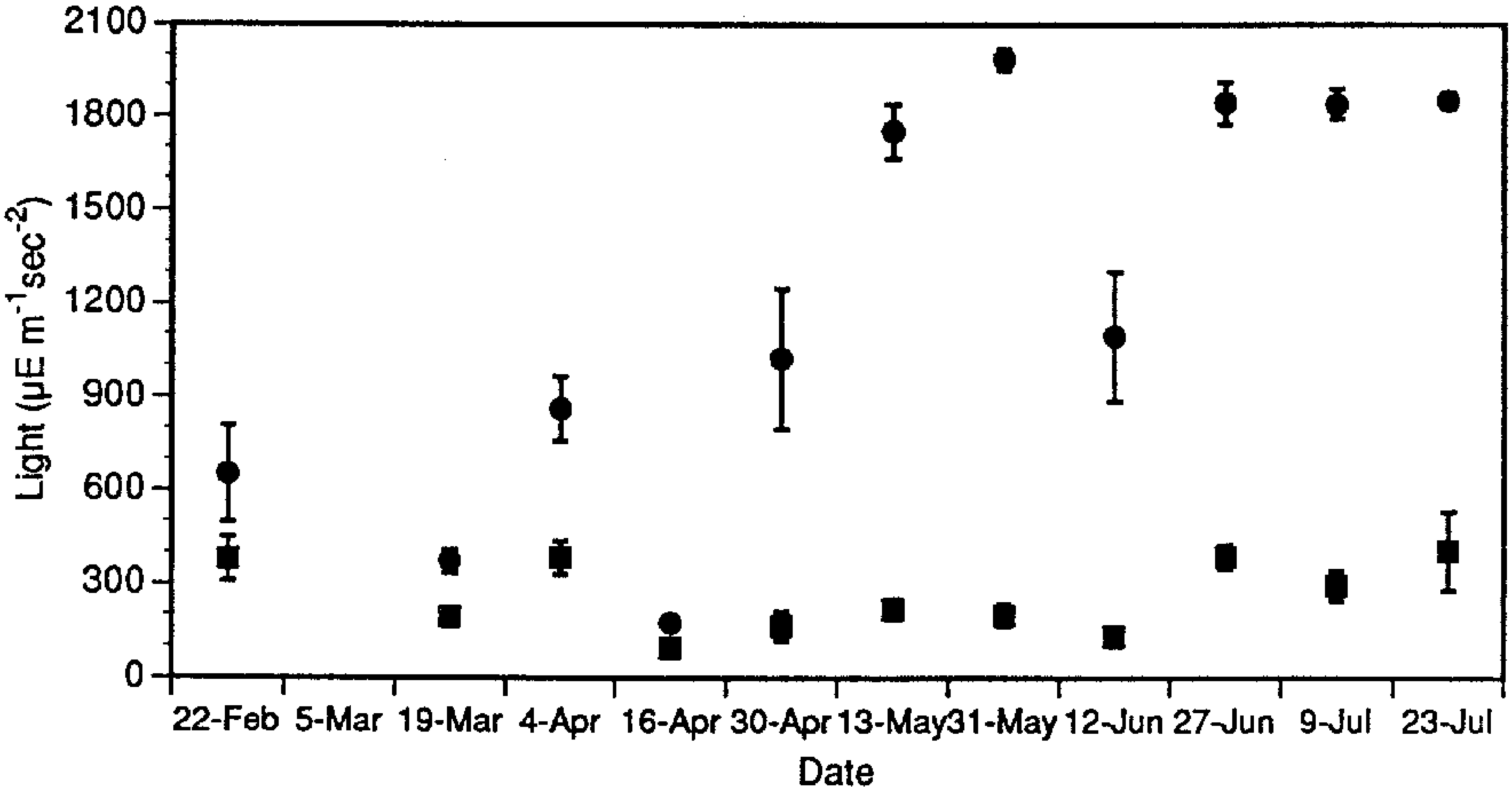

Figure 1.07. Mean ± 1 standard error of surface (●) and bottom (■) light recorded on each sampling date.

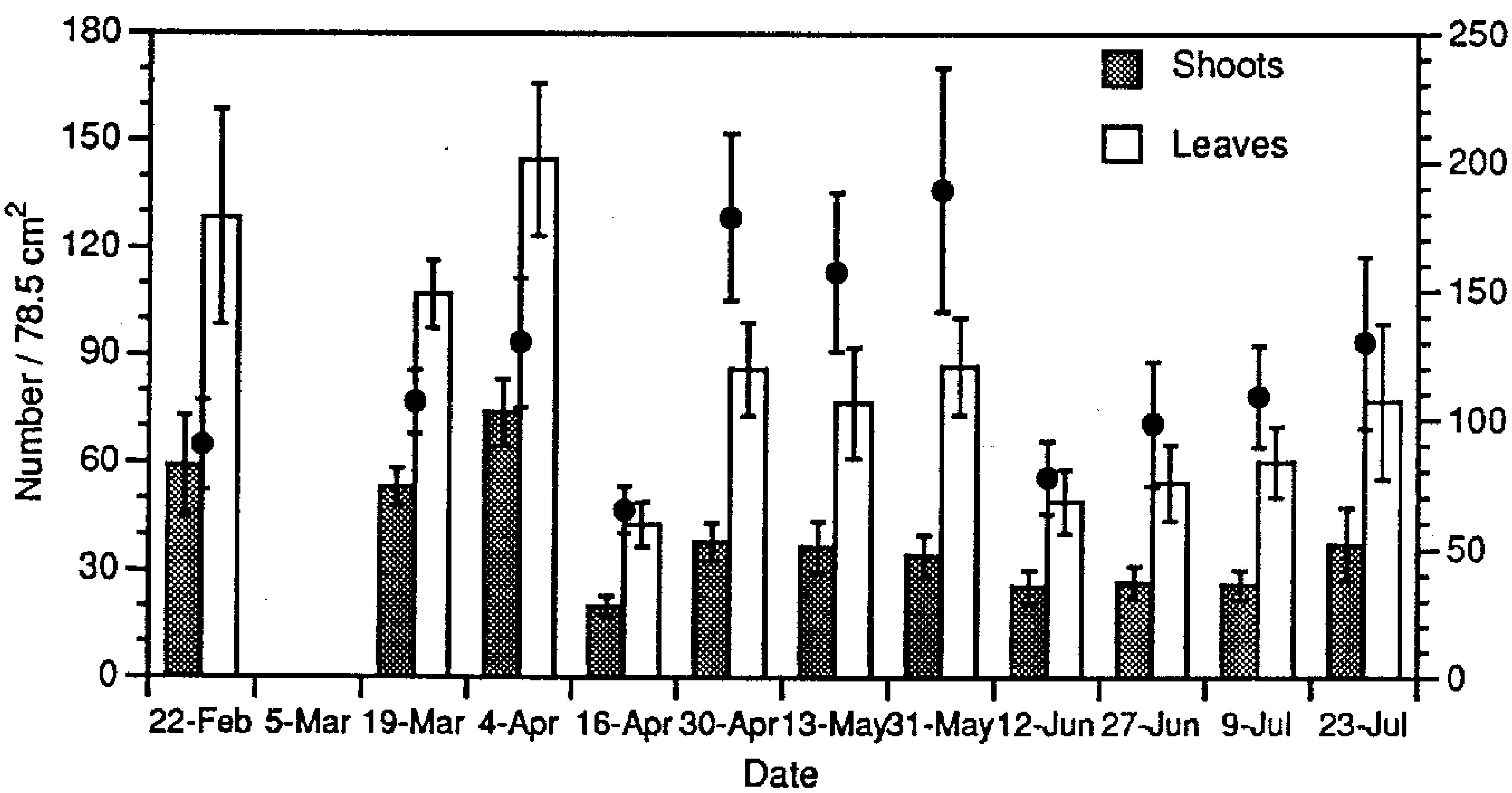

Figure 1.08. Mean ± 1 standard error of blade and shoot counts and above ground biomass (●) of *Halodule wrightii* measured for each sampling date.

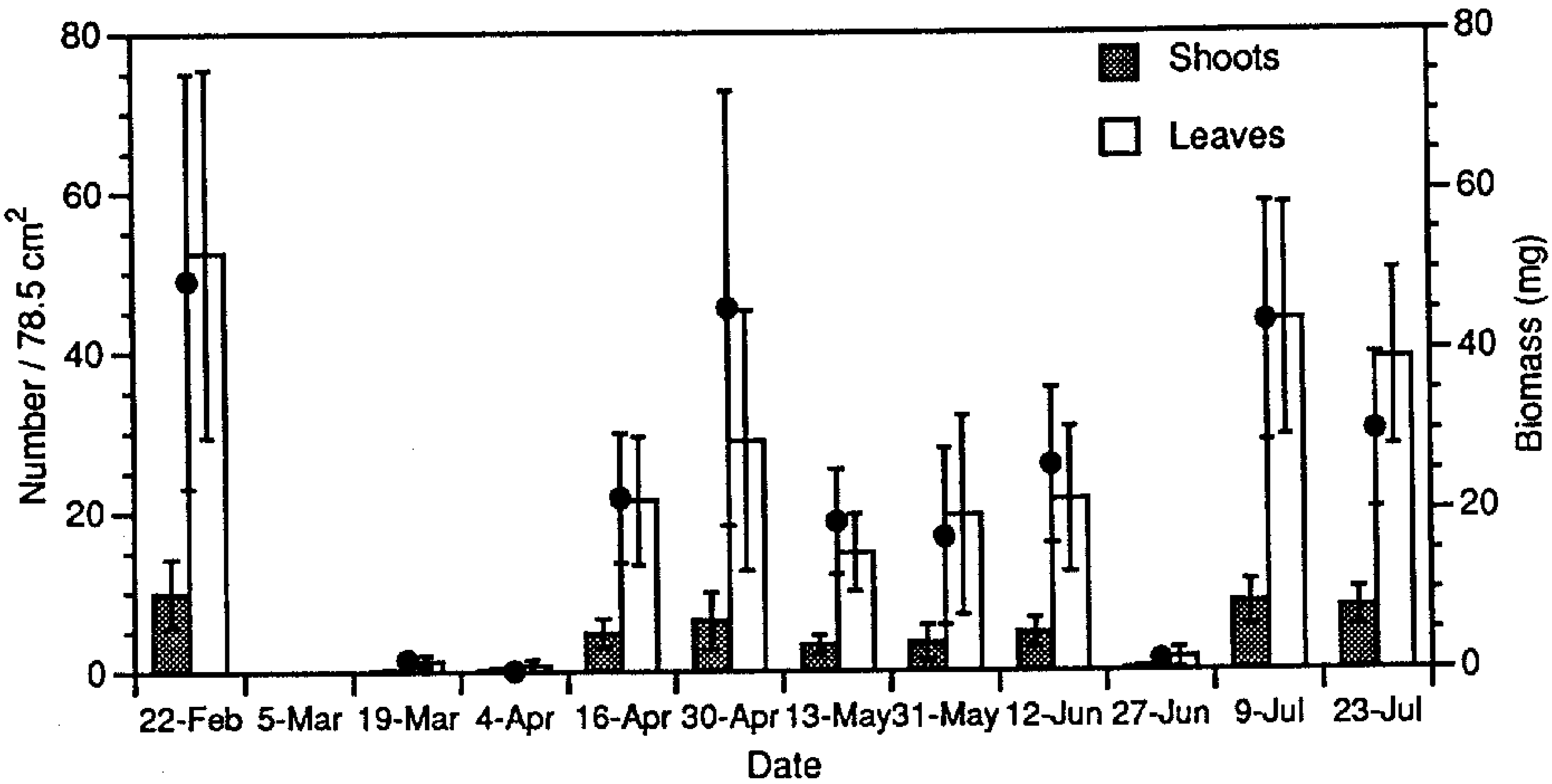

Figure 1.09. Mean ± 1 standard error of blade and shoot counts and above ground biomass (●) of *Halophila engelmanii* measured for each sampling date.

<u>Fauna collected from Cores</u> Mean density of infauna and epifauna ranged from 71 on 12 June to 244 individuals/core on 30 April. Annelids were the most abundant taxon (Table 1.02); annelids had an overall mean and standard error for all samples of 126.0 ± 6.48 individuals/core. The density of annelids was highest in February, May and July (Figure 1.10). Mean density was intermediate during March and April. Nematodes were consistently present in the samples at low densities and mean density was never higher than 14 individuals/core. These small animals may have passed through the seive, resulting in low density estimates.

The amphipods were the most abundant crustacean group in the core samples (Table 1.02). Amphipods were abundant throughout the spring, but declined in the latter part of the season, from May to July (Figure 1.11). Copepods were second in overall abundance of crustacean groups. However, the method used in collection of copepods is not typical and may underestimate their density. These copepods were mostly harpacticoids although some demersal calanoids, such as *Pseudodiaptomus* sp. were encountered. Tanaids and isopods had density peaks which occurred in April and declined to almost zero by the end of May. Their densities continued at low levels for the rest of the sampling period. Mysids were collected

Table 1.02. Overall mean densities and one standard error expressed in numbers per core for major animal groups collected in core samples for the entire sampling period from February to July (n=131).

Taxon	Mean Density	Standard Error
Annelids	126.0	6.48
Nematodes	6.6	0.75
Molluscs	1.5	0.19
Copepods	4.4	0.56
Cumaceans	0.2	0.04
Mysids	0.2	0.12
Tanaids	3.2	0.50
Isopods	1.4	0.33
Amphipods	8.5	1.02

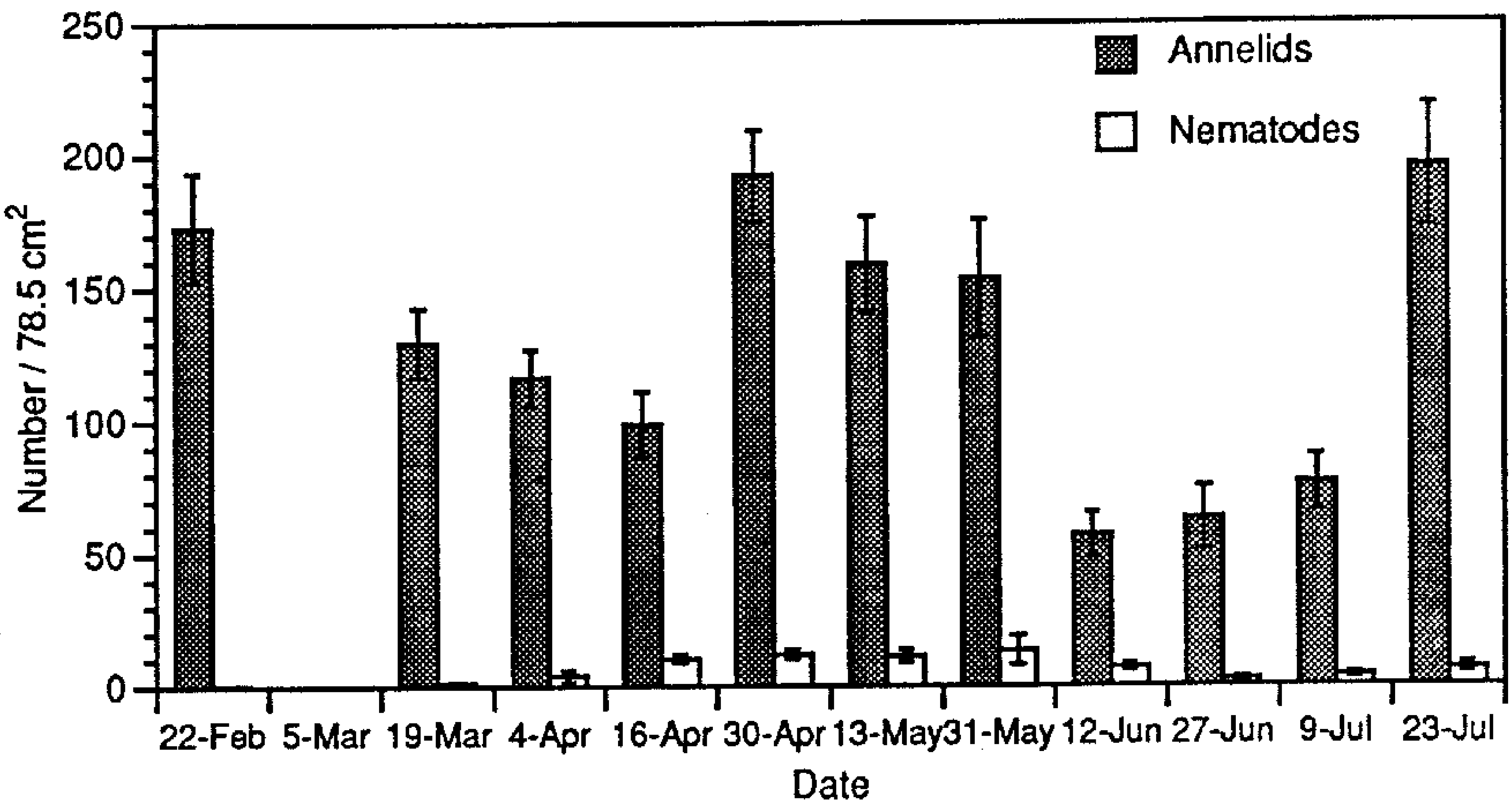

Figure 1.10. Mean ± 1 standard error of annelid and nematode density for each sampling date.

once in April and twice in July. Cumaceans were occasionally present in very low numbers. Because mysid and cumacean densities were low and occurrence was infrequent, graphic illustration is not presented.

Five species of amphipods frequently occurred and were routinely enumerated from core samples. *Ampelisca abdita* and *Cymadusa compta* were consistently present and had the highest densities. Both species had similar trends with peaks in February and April and a

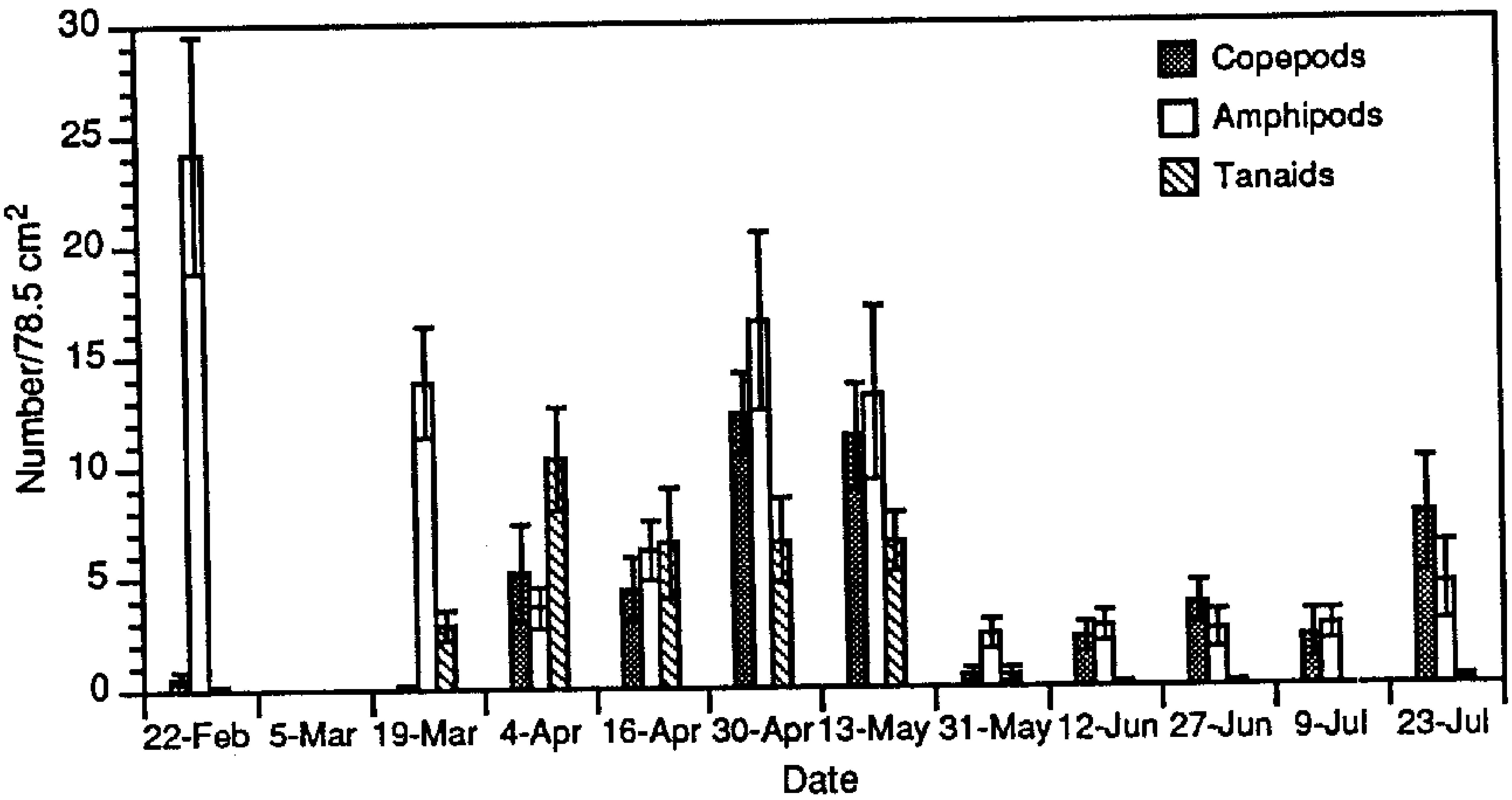

Figure 1.11. Mean ± 1 standard error of abundant crustacean groups taken from core samples on each sampling date.

decline to low mean densities in late May and through July (Figure 1.12). Mean size of *A. abdita* was relatively constant at around 3 mm TL. *Cymadusa compta* mean was similar in size (Figure 1.13). These two amphipod species are larger than most amphipod species, although their mean sizes were comparable to smaller-sized species.

Corophium sp., *Gammarus mucronatus*, and *Grandidierrella bonnieroides* densities were much lower in abundance than *A. abdita* or *C. compta*. Mean density of *Corophium* sp. was never greater than one and the species did not occur in the cores on three of the eleven sampling dates (Figure 1.14). The mean size of *Corophium* sp. was approximately 3 mm TL. Mean density of *G. mucronatus* peaked in March but declined to its lowest on 12 June and did not occur in the core samples after that time (Figure 1.15). Mean size of *G. mucronatus* was consistently around 3 mm TL throughout the sampling period. *Grandidierella bonnieroides* was the largest amphipod examined, and it occurred in low in densities (Figure 1.16). Mean density of *G. bonnieroides* peaked on 30 April; and it did not occur on two of the sampling dates. Variability in density for these species was higher, and trends are difficult to discern.

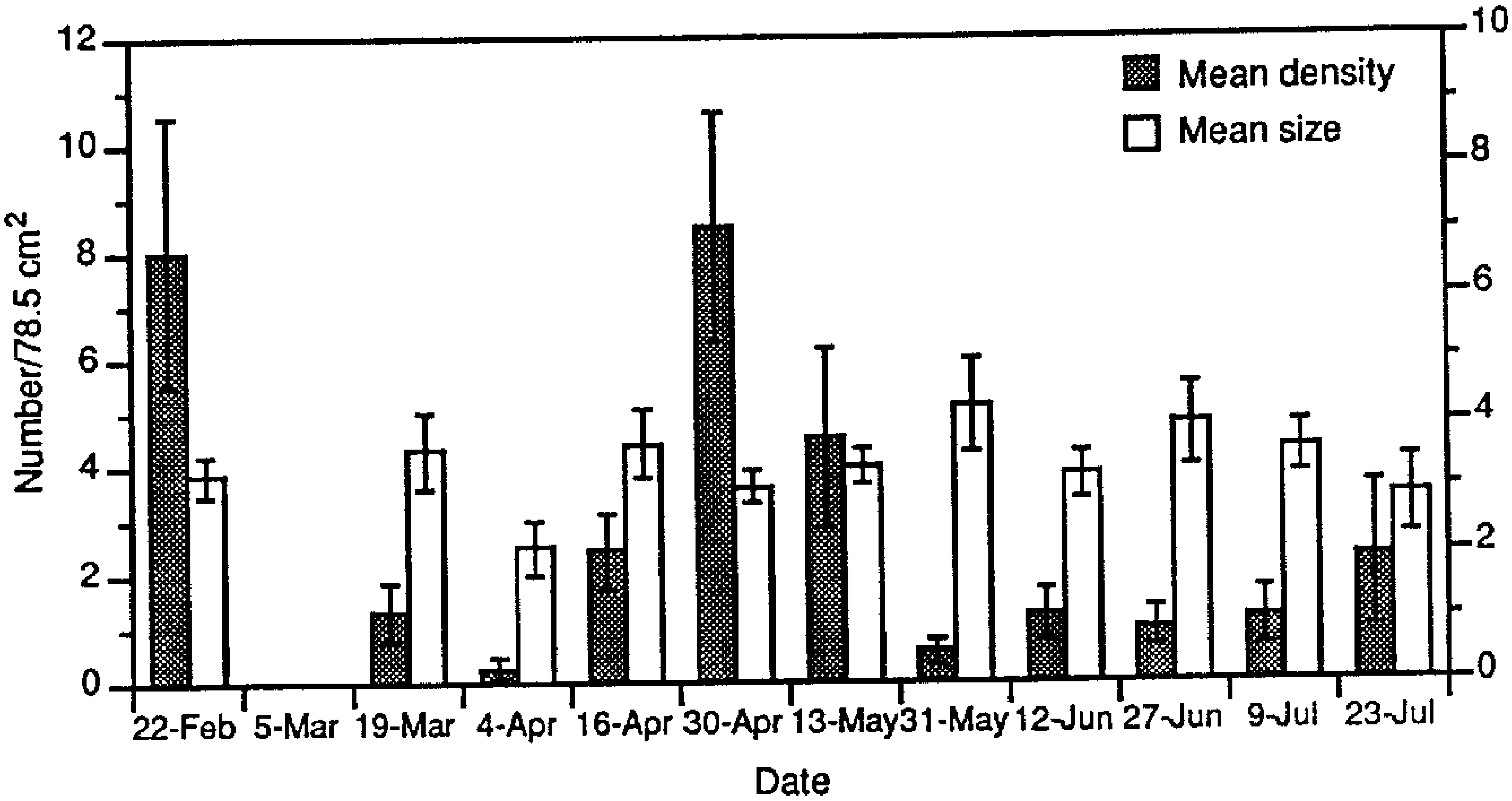

Figure 1.12. Mean ± 1 standard error of density and size of *Ampelisca abdita* for each sampling date.

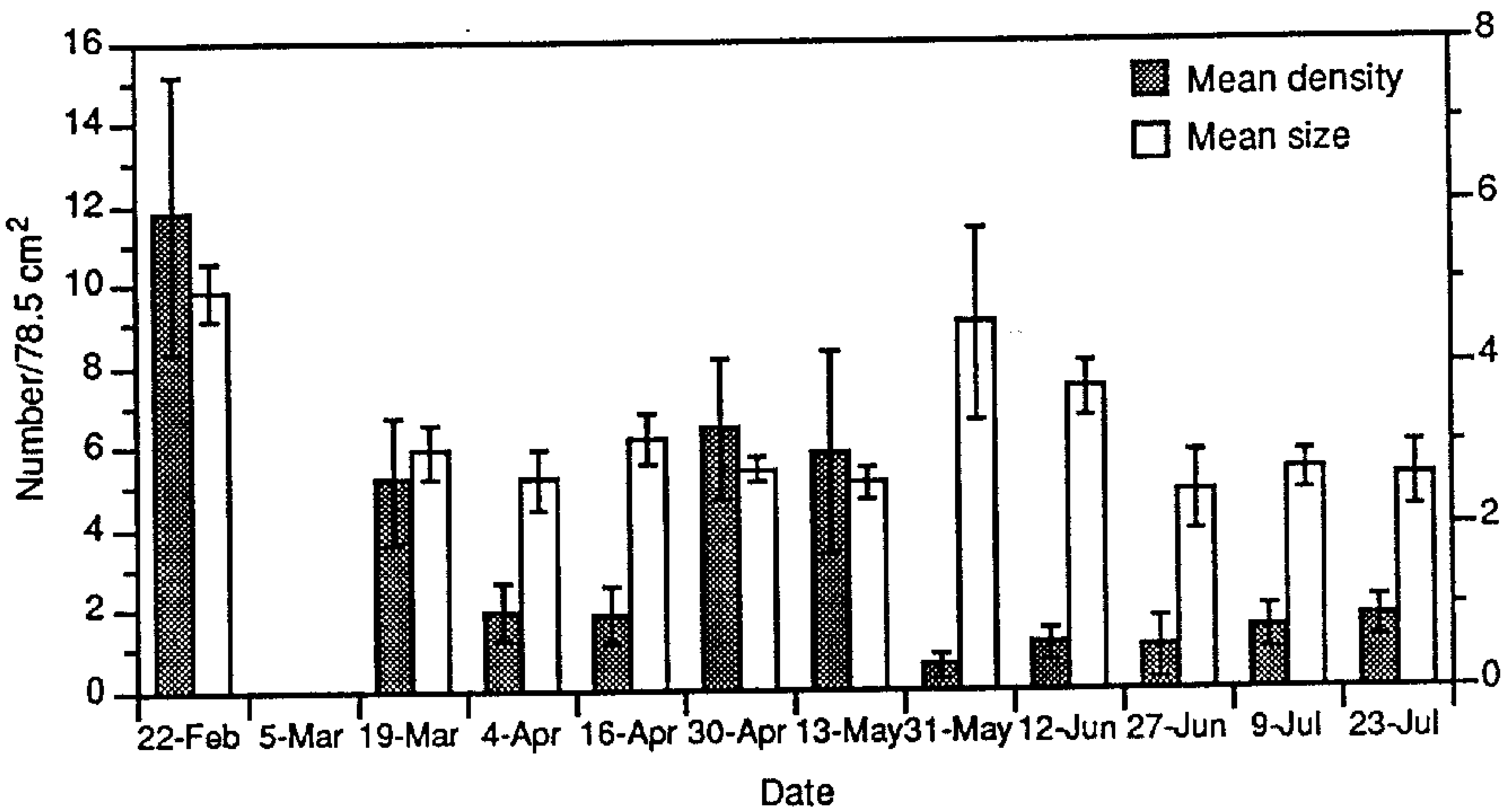

Figure 1.13. Mean ± 1 standard error of density and size of *Cymadusa compta* for each sampling date.

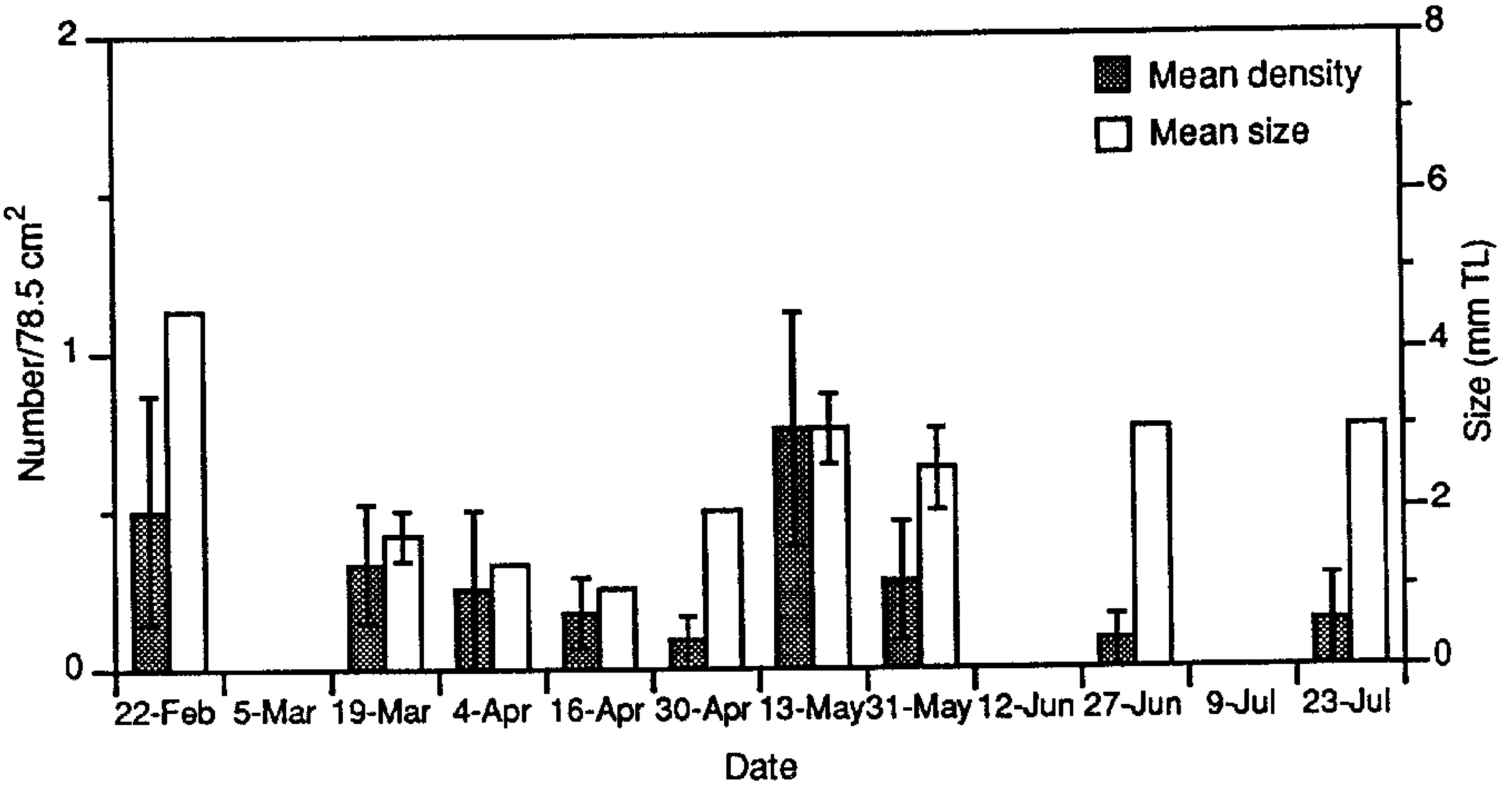

Figure 1.14. Mean ± 1 standard error of density and size of *Corophium* sp. for each sampling date.

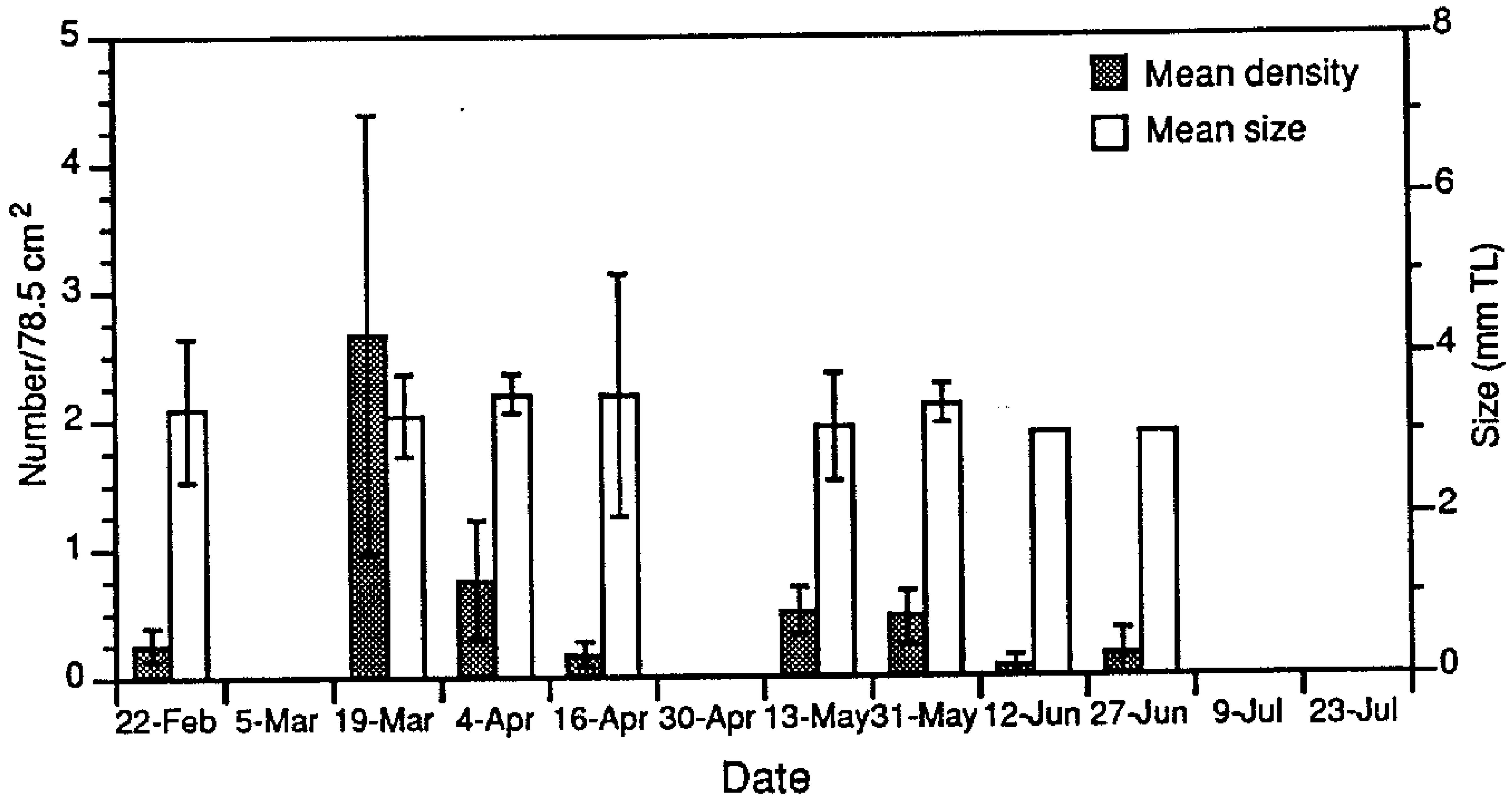

Figure 1.15. Mean ± 1 standard error of density and size of *Gammarus mucronatus* for each sampling date.

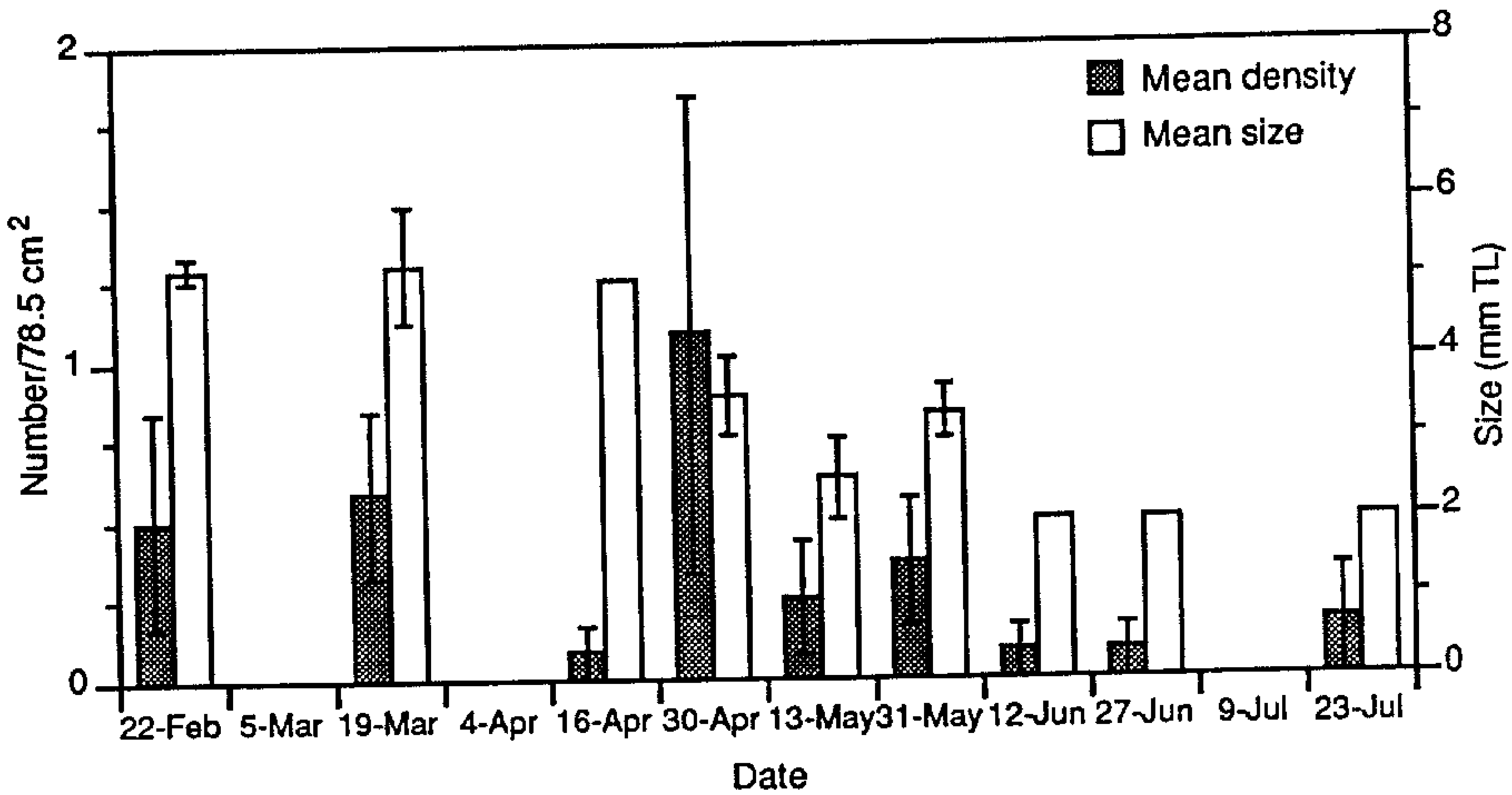

Figure 1.16. Mean ± 1 standard error of density and size of *Grandidierella bonnieroides* for each sampling date.

Macrofauna collected in drop sampler Three main groups of decapod crustaceans were abundant in the drop sampler. Penaeid and caridean shrimp had similar overall mean densities for the entire sampling period (Table 1.03). Brachyuran crabs were approximately half as dense as the two shrimp groups. Penaeid shrimp density had relatively low spatial and temporal variability and peaked in February and late May (Figure 1.17). Caridean shrimp densities were the most variable, and peaked in late June. Brachyuran crabs had low densities throughout the spring; highest densities of these crabs occurred in February and late June.

Table 1.03. Overall mean density (individuals/sample) and one standard error of decapod crustacean groups from the sampler (n=131).

Taxon	Mean Density	Standard Error
Penaeids	12.7	0.61
Carideans	12.1	1.56
Crabs	6.9	0.56

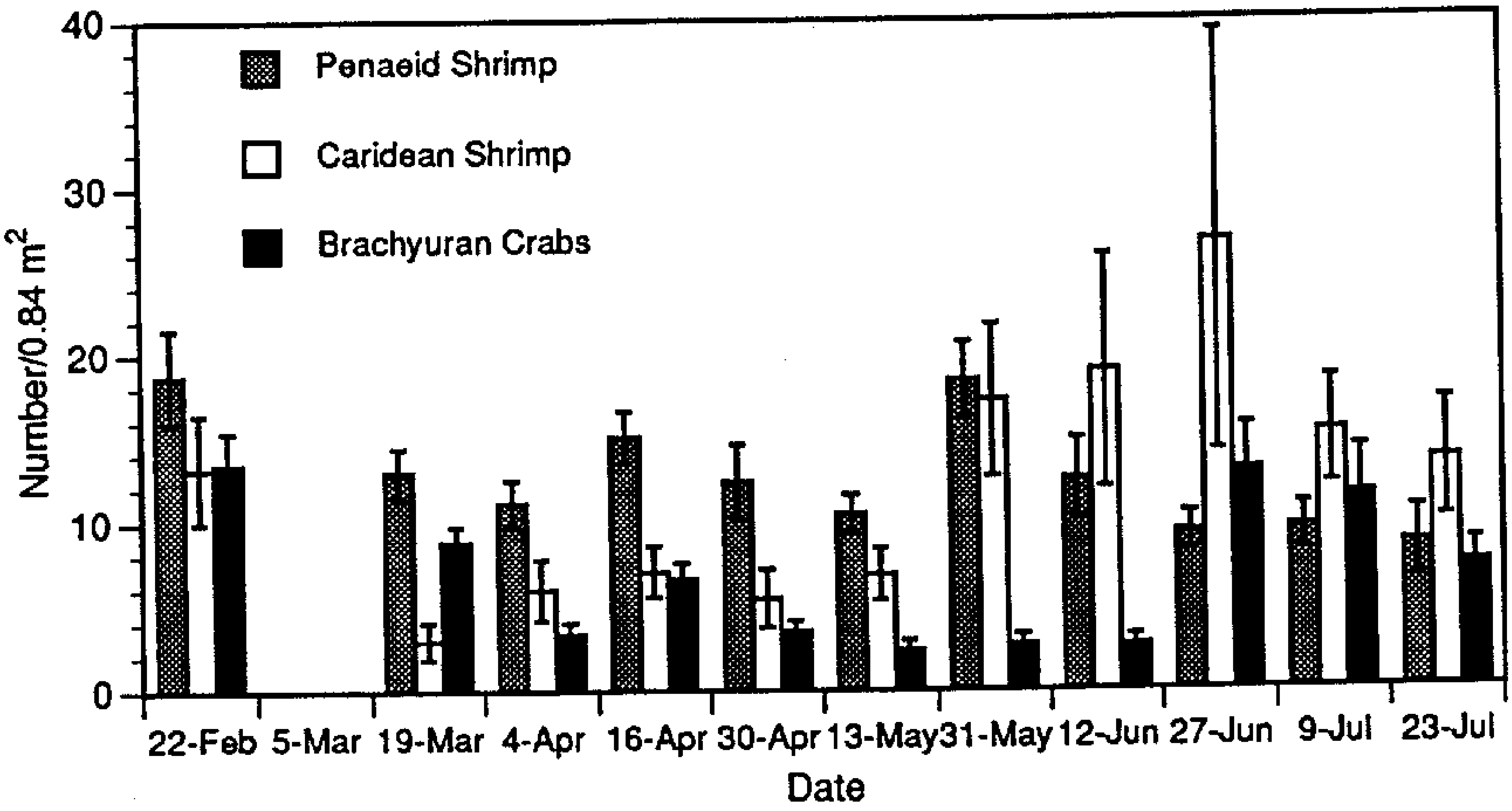

Figure 1.17. Mean ± 1 standard error of decapod crustacean density for each sampling date.

Two penaeid shrimp were relatively abundant in the drop samples during the sampling period. Mean density of brown shrimp, *Penaeus aztecus*, ranged from 7.0 to 17.6 individuals/0.84 m^2 (Figure 1.18). Mean size of brown shrimp increased throughout the spring and became relatively constant in the early summer. Decreases in mean size were associated with density peaks. This association indicates recruitment of postlarval brown shrimp, *Penaeus aztecus*, into the seagrass bed. Thus, recruitment waves were identified as occurring in February and May with a small recruitment wave in April. White shrimp, *Penaeus setiferus*, were far less abundant than brown shrimp. The density of white shrimp was low throughout the spring, occurring at less than 2 individuals/0.84 m^2, with peaks in April and July. Mean size of white shrimp was smaller than brown shrimp, with the exception of 22 February and 23 June when mean size of white shrimp peaked. Recruitment of white shrimp was indicated by an increase in density and decrease in size in June and July, although not as pronounced in this data.

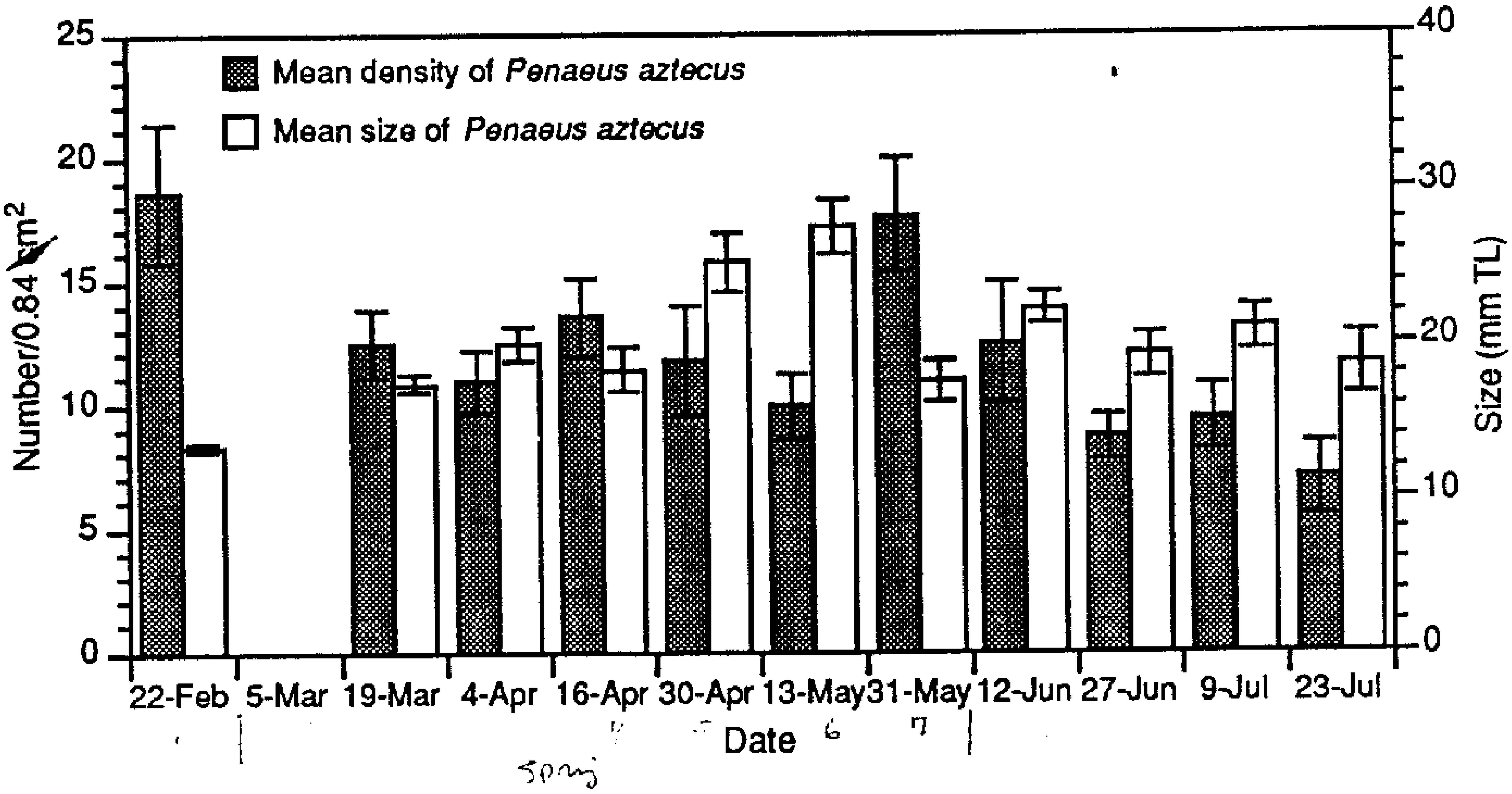

Figure 1.18. Mean ± 1 standard error of density and size of *Penaeus aztecus* for each sampling date.

Two resident caridean shrimp species were commonly encountered at high densities throughout the spring and summer in the samples. The grass shrimp, *Palaemonetes pugio*, occurred in low densities throughout the spring, increased in late May and peaked by the end of June (Figure 1.19). Mean size of *P. pugio* was highest in early spring and declined as the population increased. Another common caridean shrimp, zostera shrimp (*Hippolyte zostericola*), was also present but in low numbers. Its peak occurrence was in February. The mean size of the zostera shrimp ranged from 12.4 (31 May) to 18.5 (19 March) mm TL. Both caridean shrimp species had their lowest mean size at the same time, 31 May.

Brachyuran crabs present were from two families, portunidae and xanthidae. Portunid crabs of the genus *Callinectes* were abundant in the drop samples. No effort was made to distinguish between the blue crab, *C. sapidus*, and the lesser blue crab, *C. similis*, and this group will hereafter be referred to as blue crabs. *Callinectes sapidus* is generally the most abundant of the two species (Thomas *et al.* 1990). Peaks of blue crab occurred in February and in June. As densities decreased from the February peak, mean size consistently increased indicating little recruitment while individuals grew. The second peak in June coincided with a

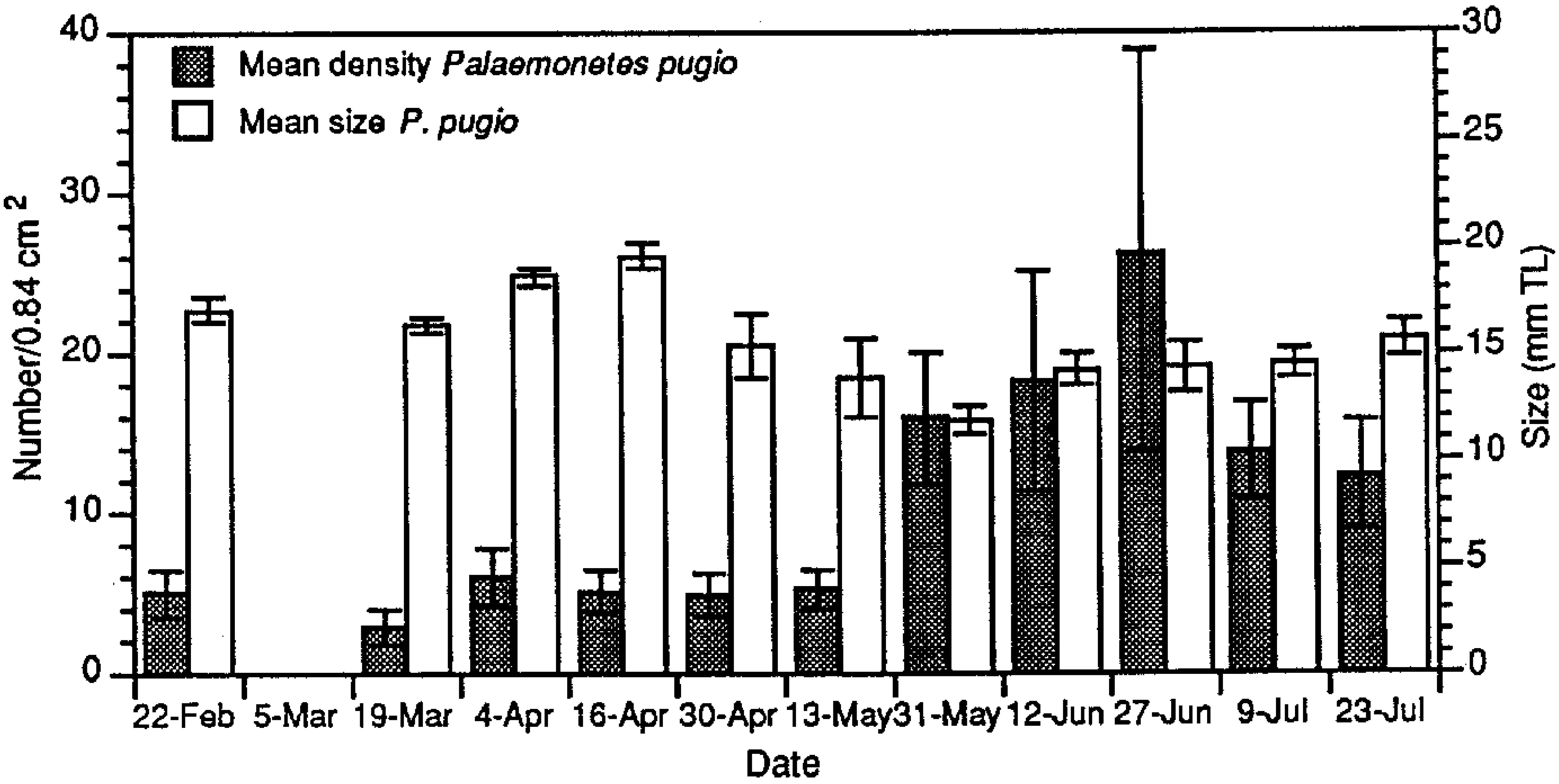

Figure 1.19. Mean ± 1 standard error of density and size of *Palaemonetes pugio* for each sampling date.

sharp decline in mean size indicating that a pulse of small recruits had entered the seagrass bed. Xanthid crabs (mostly the Harris mud crab, *Rithropanopeus harissii*) were less abundant with densities below 1 individual/0.84 m^2. These crabs were caught mainly in late spring and summer. Mean size of xanthid crabs was between 5 and 11 mm TL.

Pinfish ranked first or second in abundance among fish species throughout the sampling period (Table 1.04). Their greatest mean density, 31.7 individuals/0.84 m^2, occurred in February and continually declined to a low of 1.6 individuals/0.84 m^2 in July (Figure 1.20). Pinfish mean size increased over the sampling period. The pattern of declining density and constantly increasing size indicated that most of these fish were recruited into the seagrass meadow at the time the sampling program was initiated. Only one southern flounder, *Paralichthys lethostigma,* was caught in the drop sampler during the entire sampling period. It was caught on 22 February and had a total length of 34 mm. In this study, on a given date, an area of 10.1 m^2 was sampled. In Christmas Bay during May 1987, Zimmerman *et al.* (1990) sampled a 31.2 m^2 area, including salt marsh, nonvegetated and seagrass habitats, and only two

Table 1.04. Fish species and number of individuals caught on each sampling date. Numbers are expressed in individuals/0.84 m^2 and are ranked within each sampling date. Bold, underline and italics represent first, second and third rankings in abundance.

Taxon	Sampling Date										
	22 Feb	19 Mar	4 Apr	16 Apr	30 Apr	13 May	31 May	12 Jun	27 Jun	9 Jul	23 Jul
Ophichthidae											
Myrophis punctatus	1.8	*3.3*	*2.7*	*3.5*	*2.4*	*2.8*	*1.4*	*1.0*	*0.8*	*1.3*	*0.9*
Ophichthus gomesi	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Clupeidae											
Brevoortia patronus	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Engraulidae											
Anchoa mitchilli	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Ariidae											
Arius felis	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Batrachoididae											
Opsanus beta	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.1	0.3	0.0	0.0
Cyprinodontidae											
Adinia xenica	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Antherinidae											
Menidia beryllina	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Sygnathidae											
Hippocampus zosterae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.1	0.3	0.2
Sygnathus sp.	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.3	0.8	0.5	0.4
Sparidae											
Lagodon rhomboides	**31.7**	9.5	5.0	9.7	6.7	8.3	**3.5**	**1.7**	**3.1**	3.3	1.6
Sciaenidae											
Cynoscion nebulosus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1
Leiostomus xanthurus	*2.4*	0.2	1.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Sciaenops ocellatus	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified sciaenid	0.0	0.0	0.0	0.0	0.0	0.2	1.4	0.5	0.3	0.3	0.3
Gobiidae											
Gobionellus boleosoma	9.8	**19.5**	**27.3**	**18.7**	**17.3**	**11.7**	3.0	1.5	1.0	**3.5**	**1.7**
Gobiosoma bosci	1.1	0.1	0.0	0.3	0.5	0.3	1.6	0.0	0.0	0.3	0.3
Gobiosoma robustum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.4	0.6
Bothidae											
Citharichthys spilopterus	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Paralichthys lethostigma	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cynoglossidae											
Symphurus spp.	0.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.9
Totals	47.1	34.5	36.3	32.4	27.0	23.6	11.0	5.9	7.3	10.1	6.8

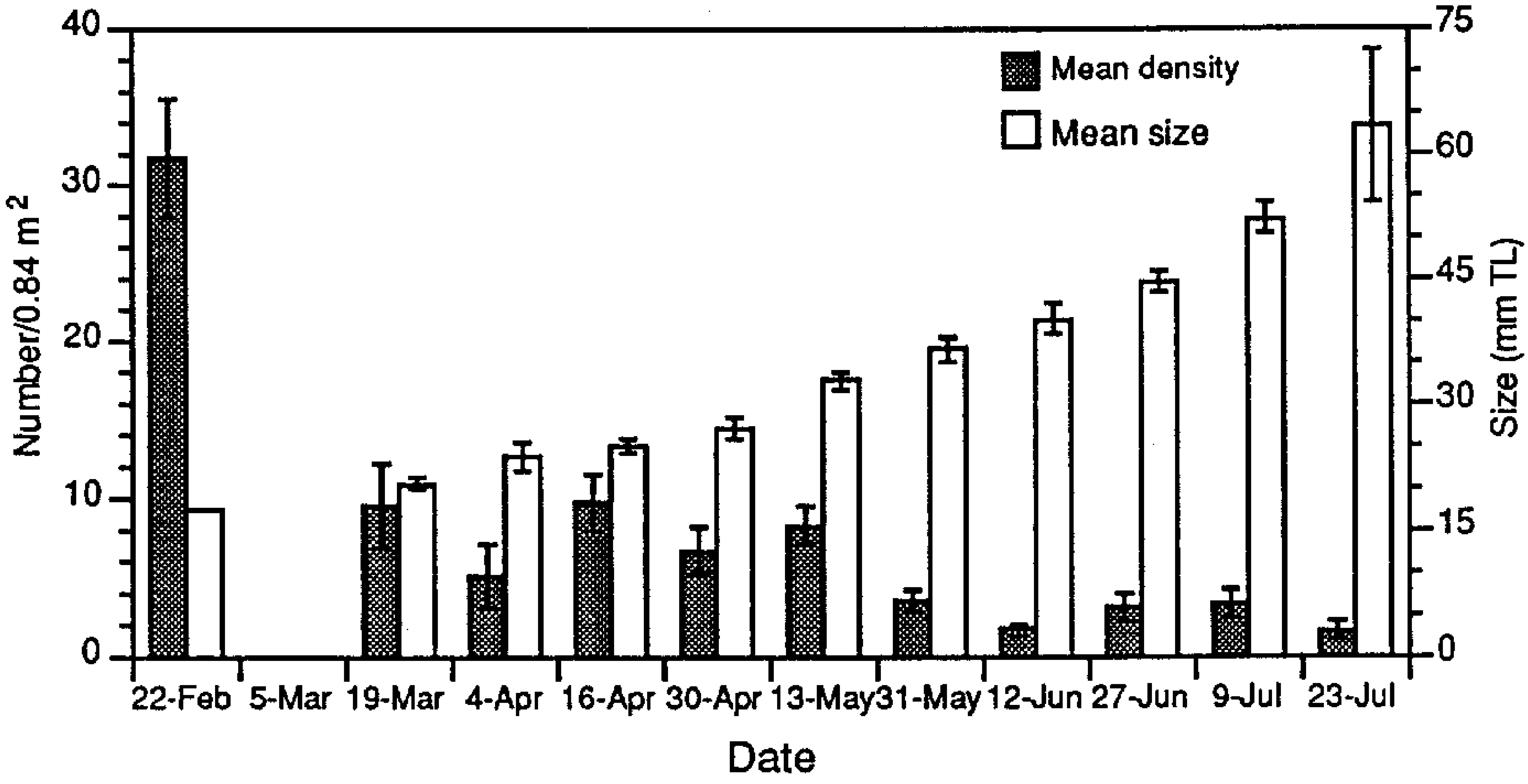

Figure 1.20. Mean ± 1 standard error of density and size of pinfish for each sampling date.

southern flounder were collected, both occurred in the nonvegetated habitat. Other fish species were collected in my study. While most of these other fish species were small and are not known to be predators of shrimp, some of these fish, such as gobies, are known predators on infauna and epifauna and may have affected densities of these groups.

DISCUSSION

Christmas Bay has an area of 1670 ha, and seagrasses, predominantly *Halodule wrightii*, cover nearly 5% of this area (Pulich and White 1990). Seagrasses are distributed on the south side of the bay, leeward of Follet's Island. Animals in the seagrass meadow are both residents and transients. The transient species are recruited from the Gulf of Mexico via Cold Pass, West Bay and San Luis Pass. An adjacent *Spartina alterniflora* marsh is utilized by the transient and more mobile species of the seagrass meadow when flooding makes it available (Zimmerman *et al.* 1990).

Changing physical conditions over the late winter, spring and early summer affect densities and distributions of the seagrasses and animals. This time period is characterized by climatic cold fronts which descend from the northern latitudes. These cold fronts are usually preceded by heavy rains and were evident in the datasonde records as periods with rapidly declining temperatures and salinities, along with increased daily ranges. Three major fronts were apparent from the mean datasonde temperature profile. The first cold front occurred around 18 March; it decreased mean temperature more than 7 °C. The salinity lagged a day and dropped 2 ‰; more variable salinity in the samples on 19 March also represents effects of the cold fronts. The second and third fronts observed in the datasonde record occurred on 13 April and 2 May. A severe cold front occurred at the end of February but was not captured in the data because the datasonde had been removed for downloading and recalibration. The remnants of this front can be seen by low, variable temperatures and salinity which gradually increased in early March. The effect of this cold front coinciding with spring neap tides was so drastic, water level had decreased dramatically and partially exposed the seagrass meadow for long periods of time. Because of this lack of sufficient water in the sampling area, samples could not be collected on the scheduled sampling date of 5 March. Plant and animal densities were lower after this severe cold front indicating a loss by mortality or emigration.

The physical conditions experienced in Christmas Bay are often near the limit of tolerance for seagrass species. *Halodule wrightii* is one of the most tolerant seagrass species of low light, variable temperature and salinity. Relatively high turbidities in Christmas Bay may cause light stress (Zieman and Wetzel 1980), and temperature in Christmas Bay can decline to 5 °C. *Halodule wrightii* has been reported to tolerate temperatures as low as 2 °C in the laboratory (McMillan 1979). Several investigators consider the seagrasses in Christmas Bay to be at the northern limit of their range (Penn 1979; Pulich and White 1990; Thomas *et al.* 1990).

Above ground biomass of *H. wrightii* was comparable to other studies in the Gulf of Mexico and Atlantic (McMahan 1968; Virnstein 1982; Zieman 1982; Pulich 1985; Thomas *et al.* 1990). The above ground biomass peak of *H. wrightii* in May and subsequent decline in the early summer was unusual. The reported annual peak for this species is generally in late summer and fall in Christmas Bay (Penn 1979; Thomas *et al.* 1990), other beds in south Texas

(Pulich 1985), and in Florida (Virnstein 1982; Zieman and Zieman 1989). Sampling in my study did not continue throughout the summer and fall, and a second and possibly higher peak may have occurred by late summer. Thomas *et al.* (1990) reported their peak in August with 96 g dry weight/m^2, three times greater than the biomass peak reported here in May. Pulich (1985) observed an above ground productivity peak in August with 190 g dry weight/m^2. His above ground biomass estimates for February to June were between 30 and 185 g dry weight/m^2. In addition, Pulich (1985) determined the importance of below ground biomass as a competing factor in phanerogam communities. Minimum percentage of below ground biomass to total biomass for *H. wrightii* was 65 % in this study, similar to his finding of 66 %.

A plausible explanation for the decline in *H. wrightii* shoots, leaves and above ground biomass in the early summer is increased consumption by the pinfish population. Pinfish diets were dominated by plant material, mostly seagrass, during this early summer period (Chapter 2). However, growth rates of *H. wrightii* are very rapid and could replace losses due to pinfish feeding activity. Virnstein (1982) demonstrated that clipped *H. wrightii* returned to the standing stock level of unclipped plants within 21 days, growing at a rate of 8.5 mm/day in the spring with a productivity of 3.0 g dry weight$\cdot m^{-2} \cdot day^{-1}$. If the pinfish were responsible for decreased plant biomass in the early summer, a declining pinfish population coupled with rapid growth of *H. wrightii*, perhaps even faster during warmer summer temperatures, could allow for an increase to peak biomass in late summer and fall.

Animals targeted in this study are common and display several different behaviors and life history strategies. The predators selected were different in abundance and feeding behavior. Pinfish are abundant and attack their prey as individuals or in schools via a search and chase technique. Southern flounder are relatively rare and feed as individuals using an ambush, sit-and-wait technique. These fish and their decapod crustacean prey are mobile species which can leave the seagrass meadow when other habitats become available, such as *Spartina alterniflora* marsh with flooding tides, and return to the seagrass when the water level ebbs. The caridean shrimp complete their life cycle in the seagrass and nearby marshes. The penaeid shrimps utilize the area for a few months as postlarvae and juveniles before emigrating to the Gulf of Mexico as subadults. Infauna and epifauna are residents of the seagrass meadow. Most of these resident species can only utilize other habitats through dispersal of their larvae. However, several of these resident species brood their young (tanaids, amphipods, isopods), which further reduces their dispersal ability. Once their larvae settle or become demersal, they are not apt to relocate.

The infauna and epifauna were the most abundant group of animals present, but were small in size. Since they do not move among habitats their changes in density patterns are more reflective of mortalities through environmental extremes or predation rather than emigration. Densities of these animals were similar to those reported by others in Florida (Santos and Simon 1974; Stoner 1980; Virnstein 1982; Sheridan and Livingston 1983). In south Texas, Huh and Kitting (1985) observed a peak in amphipod abundance in April with a decline to a summer low in August; their amphipod density estimates were much higher than in this study. The observed summer low of amphipods in the Huh and Kitting (1985) study was attributed to goby, pinfish and pipefish predation. With the exception of lower annelid densities, infaunal and epifauna densities were similar to those Thomas (1989) reported from cores taken in Christmas Bay for feeding experiments. Generally, in my study two significant declines in infauna and epifauna densities were apparent; the declines were separated by a peak in abundance during April and May. These decreases were due to mortalities, while the peak was a result of recruitment of juveniles through reproduction. The first decline was probably caused by extreme environmental conditions experienced in early March by the cold front. Low temperature, salinities and desiccation were all experienced during that period. Recruitment following this period is evident in several of the amphipod species having smaller mean sizes associated with high densities. The decline in May through June is most likely due to increased predation. Shrimp and fish have been shown to affect the distribution and sizes of amphipods (Nelson 1979; Stoner 1980; Nelson *et al.* 1982; Huh and Kitting 1985), decapod crustaceans and molluscs (Heck and Thoman 1981; Vince *et al.* 1976). Some taxa, such as mysids and calanoid copepods, had consistently low abundances because of their planktonic life mode and may have occurred only when plankton patches moved onto the seagrass meadow.

Density of the grass shrimp, *Palaemonetes pugio*, was low in the early spring but increased to high numbers in late May. This increase was principally due to reproductive effort as indicated by smaller mean sizes (Figure 1.18). The increase of grass shrimp coincided with decreases in the amphipod species in the late spring and early summer. Grass shrimp are known predators of amphipods (Nelson 1979) and may be partially responsible for the observed amphipod decline.

Postlarvae of the commercial shrimp, *Penaeus aztecus*, arrived in the seagrass meadow in typical waves illustrated by changes in mean size. Three recruiting waves were evident from the density and size data in March, April and May. Determination of decreasing densities as a result of mortality is difficult to ascertain because of replenishing numbers through recruitment, fast growth rates, and possible movement between adjacent salt marsh and nonvegetated habitats.

The pinfish is the most ubiquitous finfish species in vegetated habitats in the Galveston Bay system. Pinfish ranked first or second in abundance on all sampling dates. All juvenile pinfish recruiting into Christmas Bay had arrived by early April represented by the smallest size categories only occurring on the first three sampling dates. Pinfish mean size increased with regularity while their densities declined. The observed decline in density is a result of mortality and emigration. Although large fish, primarily sciaenids, prey on juvenile pinfish, movements to other habitats such as the salt marsh could also explain the observed decline in density. However, no records of salt marsh inundation or pinfish abundance in salt marsh habitat were made, so a test of pinfish emigrating to this habitat from the seagrass meadow can not be done.

The drop sampler/rotenone technique was a unique device designed to measure macrofaunal densities in seagrass. This drop sample technique was designed to estimate populations of small decapod crustaceans and juvenile fish although a few relatively large individuals were caught [i.e., red drum (TL=127) and hardhead (TL=123)]. The densities achieved from this sampling procedure are comparable but generally higher than findings of other investigators. The densities of both penaeid and caridean shrimp species were higher than Penn (1979) estimated for the same time of year in this seagrass bed. Penn (1979) used a beam trawl to collect decapod crustaceans. My densities of these macrofauna were also higher than those recorded by Zimmerman *et al.* (1990). They used a drop sampler and removed the water; rotenone was not used. The effect of rotenone in driving animals from burrows may account for the higher densities observed in my study. An overall mean of 9.1 pinfish/0.84 m^2 is one of the highest estimates reported. The drop sampler/rotenone combination probably gave better density estimates than more traditional methods, such as seines and trawls.

CHAPTER II

PREY SELECTION BY PINFISH AND SOUTHERN FLOUNDER DURING SPRING MONTHS

INTRODUCTION

The study of prey selection requires information on the diet of predators and the availability of prey. The diets of pinfish and southern flounder have been extensively studied in both the Atlantic and Gulf of Mexico (reviews in: Darcy 1985; Reagan and Wingo 1985; Gilbert 1986). Pinfish have been reported to switch from carnivores to omnivores and then to herbivores as they grow through the juvenile stage and mature into adults (Stoner 1980). When juveniles reach 20 mm TL they begin demersal feeding and their diet includes copepods, amphipods, shrimp and other small crustaceans. Stomach contents of the largest juveniles (>80 mm TL) are dominated by plant material. In contrast to pinfish, southern flounder are carnivorous throughout their life. Larvae feed on zooplankton (Kjelson *et al.* 1975), and small juveniles (10-160 mm TL) feed on small crustaceans, including mysids, shrimp and crabs (Diener *et al.* 1974; Stokes 1977). Larger juveniles and adults are piscivorous, but also prey on shrimp, crabs and polychaetes (Darnell 1958; Fox and White 1966; Powell and Schwartz 1979). A summary of diet information for pinfish and southern flounder from other studies is presented in Table 2.01.

Prey availability is difficult to determine, and information on availability is less frequently collected than information on diets. Variability in gear selectivity for different prey items is common, and the collection of prey and predators at different times and locations can bias study results. The patchy distribution of prey in conjunction with large sample sizes can also lead to prey densities that do not represent availability at the time of feeding. The drop sampler used in this study provides data on the environment and prey densities in the immediate vicinity of predators at the time of their capture. Although activity and digestion rates of predators must be

Table 2.01. Summary of juvenile pinfish and southern flounder diets from other studies. Abbreviations are: Amph=amphipod; Carid=caridean; Crust=crustacean; OA=other animal; Oligo=oligochaete; PM = plant material; Poly=polychaete; Serg=sergistid; Unid=unidentified.

Source	Location	Habitat & Collection	Species	Season	Fish Size	Number of Fish	Dominant Food Items (in order of Importance)								Method of Analysis
Linton (1904)	Beaufort, NC		Pinfish	Jul--Aug			Fish	Amph	PM	Mollusc	Shrimp				
Hildebrand & Schroeder (1927)	Chesapeake Bay	beach seine	Pinfish			13	PM	Crust	Mollusc	Amph					
Gunter (1945)	South Texas	Gulf of Mexico trawl	Pinfish		150-285	8/8	PM	Mollusc							FO
			S. flounder		240-490	8/16	Fish	Shrimp	Xanthid						FO
Knapp (1949)	Texas Passes	Sand/Mud purse seine	S. flounder	Summer		24	Shrimp	Fish							FO
Kemp (1950)			S. flounder			27/34	Shrimp	Fish							FO
Reid (1954)	Cedar Key, FL Tampa Bay	Seagrasses trawl & seine	Pinfish	Annual	15-50	17	Shrimp	Amph	Copepod						FO
					51-100	32	Copepod	Shrimp	Sediment	Amph	Mollusc	Crab	Fish	PM	FO
					101-128	16	Shrimp	Copepod	Amph	Mollusc					FO
Reid (1955); also in: Reid, et al. (1956)	East Bay, TX Galveston Bay	Mud bottom trawl & trammel net	S. flounder	Summer (Jun)	159-265	4/4	Fish	Shrimp							
Caldwell (1957)	Cedar Key, FL Tampa Bay	Seagrass	Pinfish			"The bulk of the food, apparently consists of small animals particularly crustaceans which seem to be associated with the usually grassy habitat of the pinfish, and the plant materials present in the stomach contents may be, at least in part incidentally ingested during the capture of the animal food."									
Darnell (1958)	Lake Pontchartrain, LA	Mud bottom trawl & seine	Pinfish	Annual	40-64	20/20	Amph	Dipteran	Shrimp	Crab	PM				%V
					65-74	21/21	Amph	PM	Dipteran	Unid	Fish				%V
					75-99	24/25	Unid	Amph	PM	Crab					%V
					100-124	19/20	PM	Amph	Crab	Unid					%V
					125-150	15/15	PM	Unid	Amph	Crab					%V
			S. flounder	Annual	113-380	14/19	Fish	Crab	Crust	Mollusc					%V
Springer & Woodburn (1960)	Tampa Bay, FL		Pinfish			57	" 11 contained exclusively, or almost exclusively, masses of Diplanthera (=Halodule), and one contained mostly Enteromorpha"								
Fox & White (1966)	Barataria Bay, LA	trawl, gig, rod&reel	S. flounder	Winter (D-F)		55/82	Fish	Shrimp	Crab						%V
				Spring (M-M)		40/55	Fish	Shrimp	Crab						%V
				Summer (J-A)		35/78	Fish	Crab	Shrimp						%V
				Fall (S-N)		41/90	Fish	Shrimp	Isopod	Crab					%V

Table 2.01 Continued.

Source	Location	Habitat & Collection	Species	Season	Fish Size	Number of Fish	Dominant Food Items (In order of Importance)								Method of Analysis
Hansen (1970)	Pensacola Bay, FL	Seagrass	Pinfish	Spring (M-M)	<76	537	Crust	Annelid	Sediment	PM	OA	Fish			%V
				Summer (J-A)	<76	887	PM	Sediment	Crust	Fish	Annelid	OA			%V
				Fall (S-N)	<76	570	PM	Crust	Sediment	Annelid	OA	Fish			%V
				Winter (J-F)	<76	122	Crust	Annelid	Fish	PM	OA				%V
				Spring (M-M)	76-173	184	Sediment	PM	Fish	Crust	Annelid	OA			%V
				Summer (J-A)	76-173	683	PM	Sediment	Crust	OA	Annelid	Fish			%V
				Fall (S-N)	76-173	575	PM	Sediment	Crust	Annelid	Fish	OA			%V
				Winter (J-F)	76-173	19	Fish	Crust	PM	Annelid	OA	Sediment			%V
Odum (1971); also in: Odum & Heald (1972)	Everglades, FL	Seagrass various nets	Pinfish	June + Sept	39-61	12	Mollusc	Mysid	Amph	PM					
Carr & Adams (1973)	Crystal River, FL	Seagrass	Pinfish	Annual	10-20	457/479	Copepod	Amph	Shrimp	Crust					%V
		H. wrightii		mixed by size	21-30	376/414	Amph	Shrimp	Copepod	Annelid	Crab	Detritus			%V
					31-40	254/292	PM	Amph	Shrimp	Annelid	Fish	Copepod			%V
		bag seine			41-50	132/146	PM	Shrimp	Crab	Copepod	Amph				%V
					51-60	159/178	PM	Shrimp	Fish	Copepod	Detritus				%V
					61-70	133/165	PM	Shrimp	Detritus	Fish	Amph	Crab			%V
					71-80	70/93	Shrimp	Fish	PM	Detritus	Crab				%V
					81-90	16/22	Shrimp	Fish	Detritus	PM	Copepod				%V
					91-110	12/17	Fish	Detritus	PM						%V
Diener, et al. (1974)	Clear Lake, TX		Pinfish	Annual	61-115	17	Amph	Sediment	Annelid	Copepod	Mysid	Mollusc	Fish	PM	FO
	Galveston Bay	trawl	S. flounder	Irregular	80-160	11	PC	Crab	Annelid	Fish	Carid				FO
Adams (1976 a, b)	Newport, NC	seagrass	Pinfish	Jan	<80 (=Juv)		PM	Copepod	Annelid	Amph					% W
		Z. marina		Feb	Tot = 118		Copepod	Amph	PM						% W
				Mar			Amph								% W
				Apr			Copepod	Amph	Detritus	Shrimp	Annelid	PM			% W
				May			Copepod	Detritus	PM						% W
				Jun			Copepod	Detritus							% W
				Jul			Detritus	Shrimp	Isopod	Copepod	PM				% W
				Aug			Detritus	Shrimp							% W
				Sep			Detritus	Amph	Shrimp	Fish	PM				% W
				Apr	80+ (=Adlt)		Amph	Copepod	Detritus	PM	Shrimp	Annelid			% W
				May	Tot = 97		Detritus	Amph	Copepod	PM	Annelid	Shrimp	Isopod		% W
				Jun			Detritus	PM	Mollusc	Fish	Annelid				% W
				Jul			Detritus	Annelid	PM						% W
			Paralichthys	Annual			Fish	Crabs	Mollusc	Amph	Detritus				% W
				Irregular	Tot = 39										

Table 2.01 Continued.

Source	Location	Habitat & Collection	Species	Season	Fish Size	Number of Fish	Dominant Food Items (In order of importance)	Method of Analysis
Brook (1977)		*T. testudinum*	Pinfish	Annual (Day)		35/35	Amph Copepod Poly Isopod	FO
		drop nets		Annual (Night)		3/5	Amph Copepod Tanaid Poly	FO
Stokes (1977)	Redfish Bay, TX	seagrass	S. flounder	Annual	10-150	242/626	Mysid Acetes Penaeid Serg Amph Megalops	FO
		seine & trawl			151+			
Kinch (1979)	Marco Island, FL	canal/channels	Pinfish	Jan	11-75	37/50	Copepod Oligo Amph Detritus Nema	% W
		beam & trawls		Jan	16-20	41/50	Oligo Amph Copepod Poly Detritus Nema	% W
		rotenone		combined	21-30	8/13	Poly Amph Oligo Copepod	% W
				combined	31-35	6/6	Amph Mysid Algae Copepod Oligo	% W
				combined	36-40	4/5	Algae Poly Oligo Mysid Crust	% W
				July	41-50	7/8	Algae Poly Fish eggs	% W
				July	51-60	5/5	Poly Detritus Amph Copepod	% W
				July	61-70	3/3	Algae Poly Detritus	% W
Powell & Schwarz (1979)	Beaufort, NC		S. flounder	Annual	100-200	206/381	Fish Mysid Shrimp Crab Amph	%V; FO
		otter trawl			201-300	21/42	Fish Mysid	%V; FO
			440		301-400	6/15	Fish	%V; FO
					>400	1/2	Fish	%V; FO
				Summer		33/45	Fish Mysid Shrimp Crab	%V; FO
				Fall		92/138	Fish Mysid Crab	%V; FO
			381	Winter		42/150	Fish Mysid Amph	%V; FO
				Spring		39/48	Fish Mysid Crab	%V; FO
Levine (1980)	L. Pontchartrain, LA	trawl, seine, gill	Pinfish	Annual	56-124	14	Copepod Amph Xanthid Annelid Insect PM	FO
		& trammel nets	S. flounder	Annual	102-335	4	Fish Amph	FO
Stoner (1980)	Appalachee Bay, FL	seagrass	Pinfish	Annual	11-15		Copepod Invert eggs	% W
	trawl	*T. testudinum*			16-35		Amph Copepod	
		S. filiforme			36-80		Amph Copepod Shrimp Epiphyte	
					81-120		Epiphyte Amph Poly Isopod	
					>120		Epiphyte PM	
					(mm SL)			
DiVita, et al. (1983)	Gulf of Mexico, TX	trawl (O II)	Pinfish	Summer (J-J)	91-147	6/24	Detritus	FO
			S. flounder	Summer (J-J)	138-265	9/14	Detritus Penaeid	FO
Minello, et al. (1989b)	Lavaca Bay, TX	Spartina marsh	Pinfish	Spring (May)	36-88	6	PM Annelid Crust Amph Copepod Fish Tanaid Mysid	% W
	San Antonio Bay	Non Vegetated		Summer (Aug)	65-118	153	PM Copepod Tanaid Amph Crust Annelid	% W
				Fall Oct)	96-138	37	PM Crab Penaeid Mysid Amph	% W
		Drop sampler	S. flounder	Spring (May)	50-119	14	Penaeid Mysid Crust Carids Amph	% W
				Summer (Aug)	77-355	5	Mysid Fish	% W

considered, the prey in the immediate vicinity at the time of capture should be one of the best indicators of prey availability. The objective of this portion of the investigation was to examine diets of these predatory juvenile fish over the sampling period, compare diets with prey availability, and identify prey selection by pinfish and southern flounder.

A variety of prey selection indices have been developed to determine whether prey species are consumed more frequently than their occurrence in the environment. Desirable qualities of a selection index are: 1) zero represents random feeding, 2) a deviation from randomness should be symmetrical around zero (the same magnitude of change regardless of sign), 3) changes in food availability or usage should have the same effect on the index regardless of their levels (linear effects), 4) feeding upon rare prey types should not markedly affect the index, and 5) the index should be amenable to statistical testing (Lechowicz 1982). Many indices are based on the forage ratio, which is simply the ratio of a particular prey item in the diet to its abundance in the environment (Manly *et al.* 1972; Jacobs 1974; Manly 1974; Chesson 1978; Vanderploeg and Scavia 1979). One such index, electivity (E'), the selection index developed by Ivlev (1961), has been the standard of predator-prey investigations. Selection indices based on the forage ratio are nonlinear, and statistical methods for testing prey preferences are generally unavailable. Rare items or changes of prey abundances in the environment can also disproportionately affect these indices (Strauss 1979).

The linear index, Li (Strauss 1979, 1982), is not based on the forage ratio. The Li for prey item i is calculated by subtracting the ratio of prey i in the environment, p_i, from the ratio of prey i, r_i, in the diet, $Li = r_i - p_i$. Theoretically, this index is linear and normally distributed, which allows testing prey preferences against the null hypothesis of random feeding (Ho: Li = 0) or testing differences in selection for prey items (Hansen and Wahl 1981). The index ranges from -1 to +1, with negative values representing avoidance of prey, zero representing random feeding, and positive values representing preferred prey.

MATERIALS AND METHODS

Stomach contents were examined for 326 pinfish collected in the drop samples. Only fish greater than 25 mm TL were examined because by this size they have completely switched to demersal feeding. The stomachs were removed through dissection, and a subjective estimate of fullness was made; fullness was rated on a scale of 0 (completely empty; thick stomach wall with folds) to 4 (completely full, usually depicted by a very thin stomach wall and no folds). Food items were teased away from the stomach tissue, identified, categorized, measured to the nearest mm TL if they were crustaceans or fish, and placed in a pre-weighed aluminum pan for drying. The prey categories identified are listed in Table 2.02. Individual prey categories from each fish were placed in separate pans. Unidentified material consisted of detritus or plant material lacking chlorophyll. Both the stomach contents and the fish predators themselves were dried at temperatures of 100-105 °C for a minimum of 24 h, to obtain constant weight, and dry weights were measured with a Sartorus Analytical Balance Model 2400 measuring to the nearest 0.1.

Density estimates for prey in the drop sampler were used to assess prey availability. Infauna and epifauna abundances were determined from the cores taken within the sampler. All prey densities were converted to number per square meter. Only prey which were less than half of the mean pinfish size on that sampling date were used in calculating the observed prey density in the environment.

Linear indices were calculated for prey of interest for each individual predator in a drop sample. The percentage of a particular prey item (by numerical abundance) was determined in relation to other prey in the stomach, and a comparable percentage was calculated for prey in the drop sample. The linear index is simply the difference between these percentages. The mean index for all predators in a sample (sample index) was then determined. To check for normality of these sample indices, I calculated residuals from the overall means on each sampling date and tested the distribution of all residuals from the sampling period (n=91) against a normal curve using PC SAS algorithms. For most prey items the distributions were highly

Table 2.02. Example from stomach analysis data sheet illustrating prey categories, codes, number, dry weight and percent composition of prey item. Peracarid and decapod crustaceans and fish prey were measured to the nearest millimeter. Only weight was determined for shaded categories .

Sample Date: 30-April-1986	Rep: 0.01				
Fish Species	Pinfish				
Total Length (mm)	32				
Dry Weight (mg)	78.7				
Stomach Fullness (0-4)	2				
Prey Items:	CODE	Tot.	% No.	Wt	% Wt.
Penaeus aztecus	P1		0		0
Penaeus setiferus	P2		0		0
Total Penaeids	PT		0		0
Amphipods: Unidentified	A0		0		0
Ampelisca abdita	A1		0		0
Corophium sp.	A2		0		0
Cymadusa compta	A3		0		0
Gammarus mucronatus	A4	1	14.29	0.8	22.22
Grandidierella sp.	A5		0		0
Total Amphipods	AT	1	14.29	0.8	22.22
Tanaids	C1		0		0
Mysids	C2		0		0
Copepods	C3	6	85.71	0.9	25.00
Isopods	C4		0		0
Callinectes sapidus	C5		0		0
Palaemonetes pugio	C6		0		0
Other Carideans	C7		0		0
Unidentified Crustaceans	C8		0		0
Other Crustaceans	C9		0		0
Annelids	WM		0		0
Other Animals	OA		0		0
Unidentified Animals	UA		0		0
Fish	FS		0		0
Plant Material: Algae	AG		0		0
Macrophyte	PM		0		0
Unidentified Foods	UN		0	1.9	52.78
Sediments	SD		0		0
TOTAL {Wt(mg)}		7	100	3.6	100

skewed and non-normal. In addition, Levene's Test for homogeneity of variance (Sokal and Rohlf 1981) indicated that variances for the sampling dates were heterogeneous, and this may have caused the lack of normality in the residuals. Tests for normality of the index with sampling dates also indicated a significant depature from normality, even though these have low power (n=12). Because the initial values used to construct the index were percentages, an arcsine transformation was used on the original percentages from the diet and environment to help restore normality. The modified linear index (MLI) ranged from -1.57 to 1.57, where zero represents random feeding. The MLI was tested for normality, and for most prey species and sampling dates there was no significant (5 %) departure from normality. Ninety-five percent confidence limits were calculated to test for significant differences from zero or random feeding.

Only one southern flounder was collected in the drop samples. Additional specimens were obtained from a drop sampling program conducted by the National Marine Fisheries Service during the Spring 1985 in the same seagrass meadow in Christmas Bay. Densities of all prey items were not determined from this sampling program; therefore, only general diet information is presented, and linear indices were not calculated.

RESULTS

Stomach Contents of Pinfish and Southern flounder

Pinfish More than 98 % of the pinfish examined contained something in their stomachs. The greatest number of fish examined occurred in late April and early May (Table 2.03). Mean stomach fullness of pinfish for each sampling date ranged from 1.28 to 2.14. Generally, higher fullness ratings were experienced in the early spring declining to lows in the early summer. On the first sampling date, only 4 pinfish exceeded a size of 25 mm TL; therefore for that sampling date pinfish greater than 20 mm total length were examined. Pinfish consumed both plant and animal material throughout the sampling period (Figure 2.01). In addition, a large portion of the diet was unidentified material. The proportion of plant material in the diet increased throughout the sampling period, and concurrently the animal portion decreased. Sediments were found in the stomach contents on two sampling dates but were not a major dietary component.

Copepods were the most numerous organisms in the animal portion of the diet (Figure 2.02). When present, copepods made up at least 75% of the animal portion by number, but the group was not present on 19 March and 4 April. Copepods were not generally identified to species, but both harpacticoids and large bodied calanoids, such as *Pseudodiaptomus*

Table 2.03. Number of pinfish examined, those with food and mean stomach fullness is shown for each sampling date.

Pinfish Characteristics	Date 22 Feb	19 Mar	4 Apr	16 Apr	30 Apr	13 May	31 May	12 Jun	27 Jun	9 Jul	23 Jul
Number Examined	22	12	14	35	53	48	32	19	37	36	18
Number with Food	20	10	13	35	53	48	32	19	37	35	18
Stomach Fullness	2.09	1.75	1.79	2.14	1.76	1.73	1.38	2.00	1.97	1.61	1.28

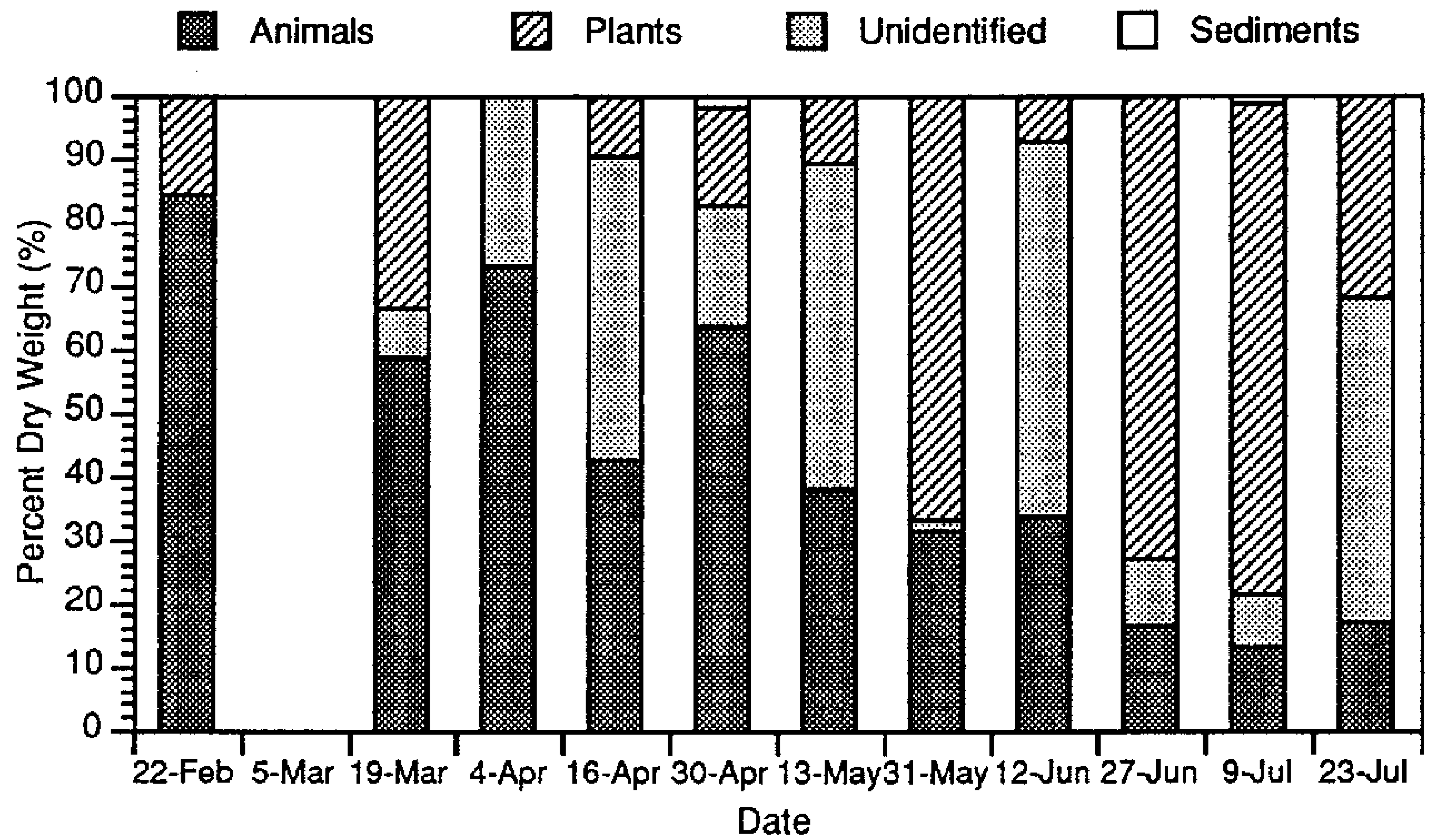

Figure 2.01. Percent dry weight of major food categories in pinfish stomach contents is shown for each sampling date.

cornatus, were common in this group. Annelids and peracarids (peracarids include the following groups: mysids, tanaids, isopods, and amphipods) were also numerically abundant in the diet of these fish. Shrimp (both penaeid and caridean) occurred in diets mostly in the late spring and summer months. The category "All Others" included crabs, fish and unidentified animal remains; its contribution by percent number was greatest on 19 March and consisted of unidentified animal remains.

A comparison of these same animal categories by dry weight revealed a decrease in the contribution by copepods with an increase in contribution by annelids (Figure 2.03). Copepod contribution by dry weight was greatest on 12 June and 23 July at 50 %, but usually it was less

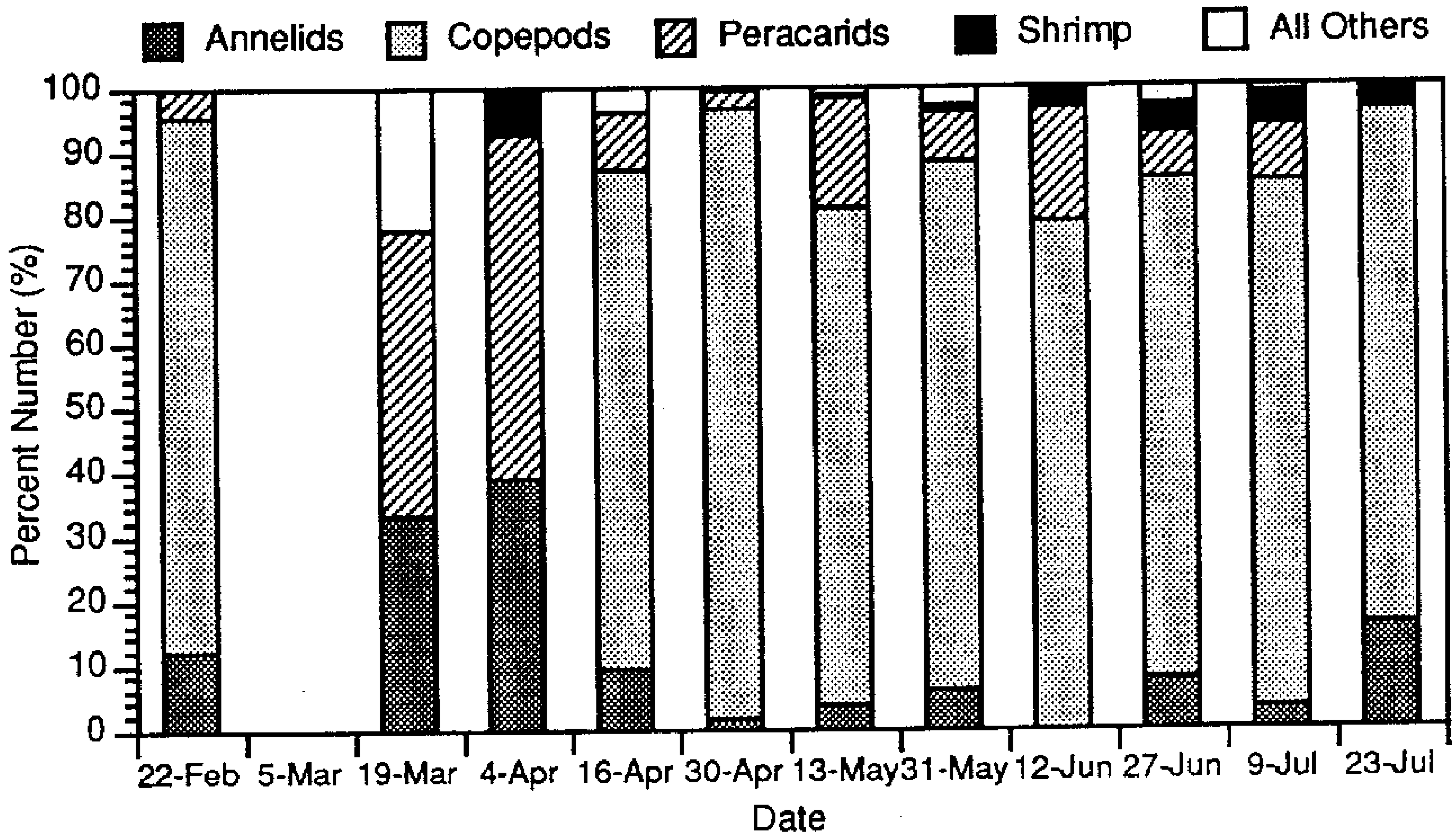

Figure 2.02. The percentage (by number) of major animal categories in the stomach contents of pinfish for each sampling date. Peracarids include cumaceans, mysids, tanaids, isopods, amphipods; Shrimp includes penaeid and caridean shrimp; and All Others includes crabs, fish and unidentified animal material in which unidentified animal material made up the bulk of the category.

than 30 %. Annelid contribution by dry weight ranged from 0 to 85 %, peaked in early April and was lowest in June and early July. In comparison with numerical abundance, the importance of peracarids and shrimp in diets increased when determined by weight. This increase was due to the relatively large size of these prey in relation to copepods.

In a more detailed analysis of the relative dietary contribution of selected crustaceans, the percentages (by number) of amphipods, tanaids, penaeid and caridean shrimp were examined. Among these prey, amphipods were the most abundant and were represented throughout most of the sampling period (Figure 2.04). Tanaids largely contributed to the diet on 19 March and 4 April; they had a minor contribution in late May and early June. Caridean shrimp were important on one date in the early spring and occurred again in the summer. Penaeid shrimp did not become important until the late spring and continued to be important into the summer.

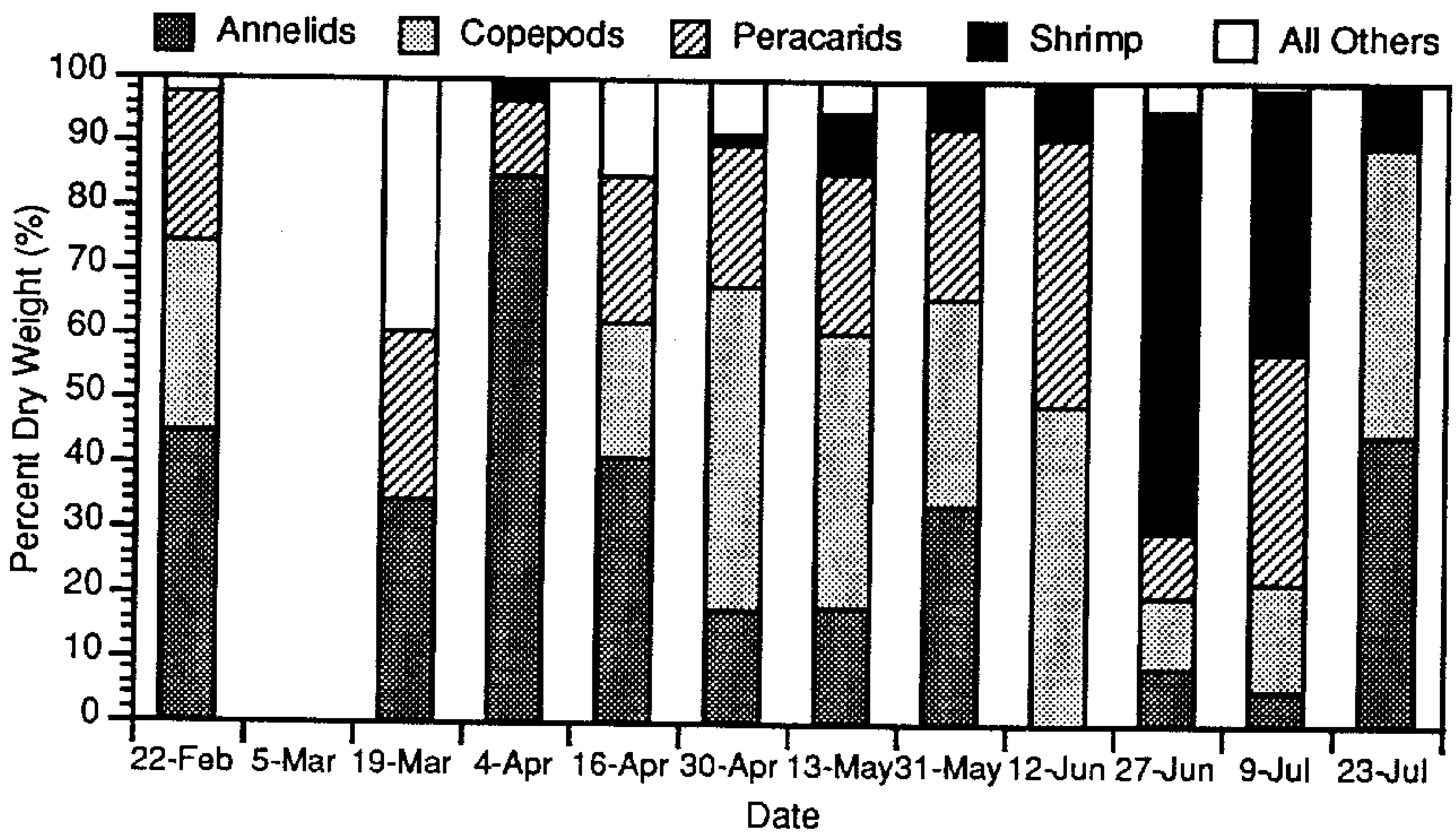

Figure 2.03. The percentage (by weight) of major animal categories in the stomach contents of pinfish for each sampling date. Plant material was excluded from this analysis, and percentages were based on the total dry weight of animals consumed. Categories are the same as those in Figure 2.02.

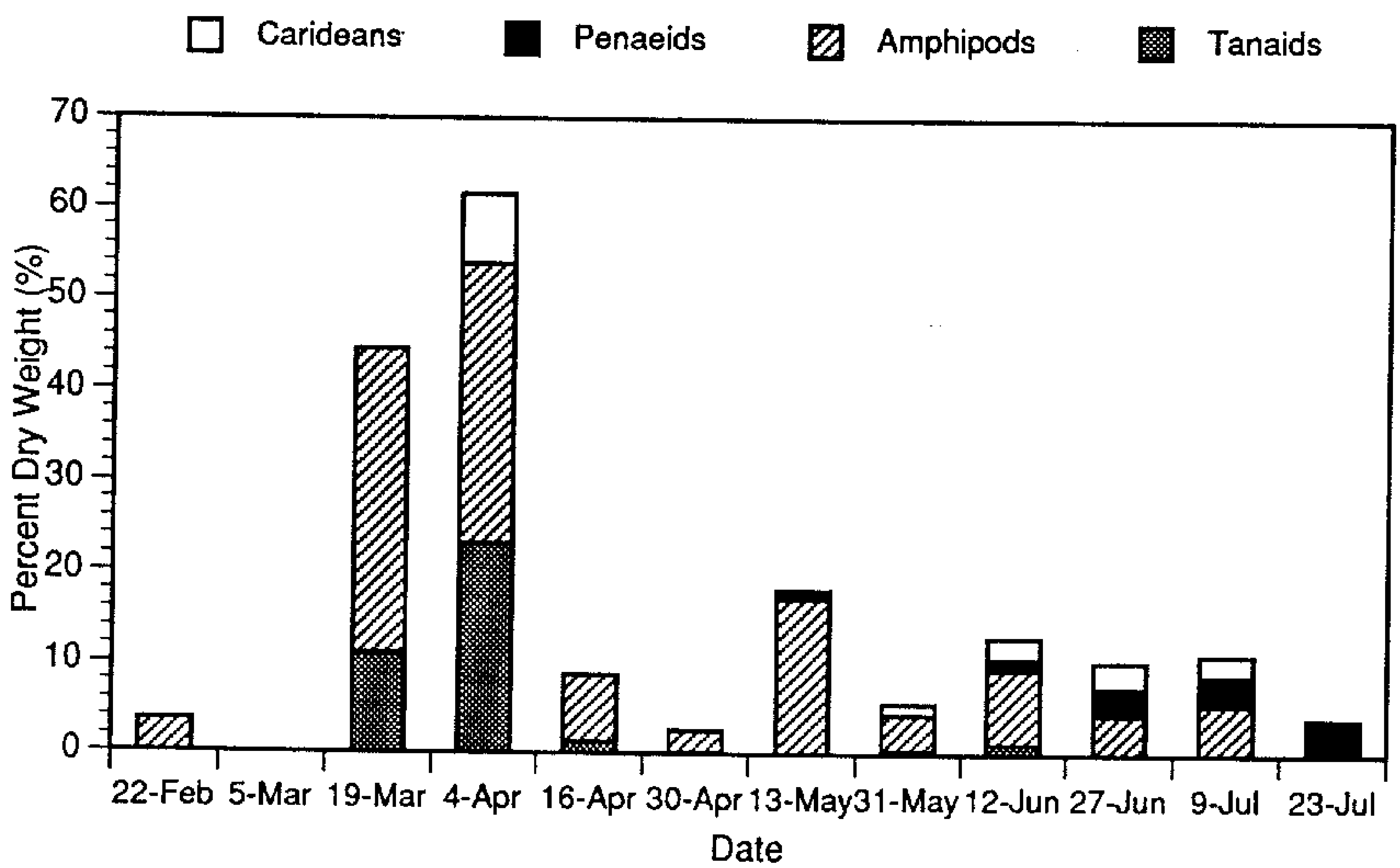

Figure 2.04. Percent by number of select prey items of interest in the stomach contents of pinfish for each sampling date.

Southern flounder The stomach of the one southern flounder collected within the drop sampler contained four small pinfish. These prey ranged in size from 10 to 15 mm TL and had a total dry weight of 4.0 mg.

Twelve southern flounder collected during February to May 1985 ranged in size from 15 to 116 mm total length. The five collected in late February 1985 were all less than 30 mm TL, and their stomach contents consisted entirely of annelids (Figure 2.05). Five of the remaining seven had food in their stomachs. On 26 March, three southern flounder (30-44 mm TL) had eaten mostly amphipods and penaeid shrimp. And near the end of April, two fish (70-116 mm TL) had eaten fish and penaeid shrimp.

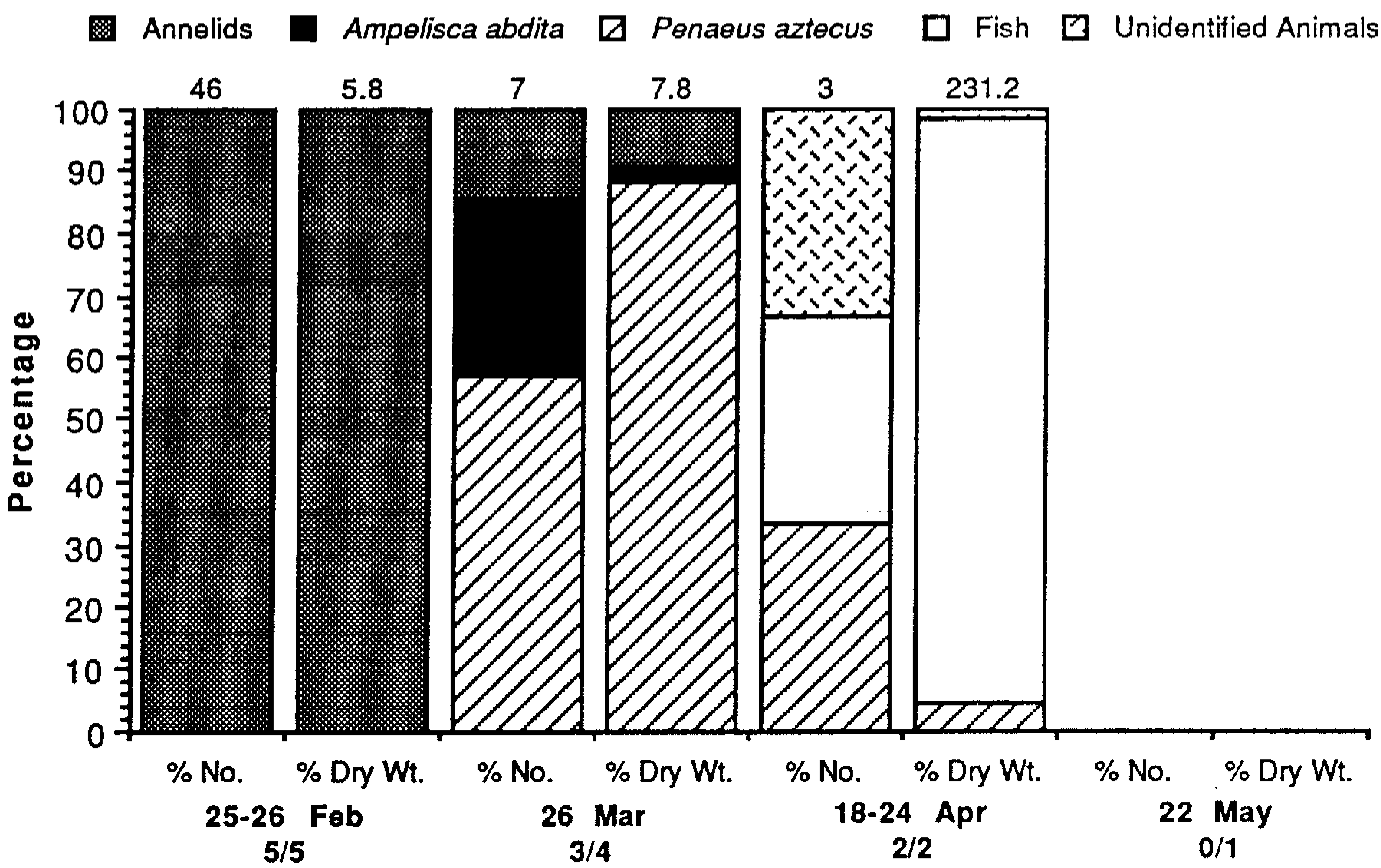

Figure 2.05. Percentage by number (%No.) and dry weight (% Dry Wt.) of animal food categories in stomachs of southern flounder collected in the Spring, 1985. Below each date is a ratio of the number of fish with food in stomachs over the total number of fish examined. The number at the top of each bar represents the total number of prey and total dry weight of those prey for each date.

Prey Selection by Pinfish

Prey selection was examined within the animal portion of the diet by comparing the percentage (by number) of prey in the diet with the percentage in the environment. The percent in diet, percent in environment and modified linear index were determined for each sampling date . Over 98% of the prey consumed were either annelids or crustacea, and the remaining portion of the diet was fish, molluscs, nematodes and platyhelminths.

Copepods occurred more frequently in the diet than in the environment (Figure 2.06). Mean percent of copepods in the diet was variable and ranged from 0 to 74 %. No copepods were found in the stomachs of pinfish on two dates in March. In the environment, densities of copepods were low and this group never made up more than 10 % of the available prey. Because of high occurrence in the diet and low frequency in the environment, the modified linear index was significantly positive for copepods on 6 of the 11 sampling dates. The MLI was not significant in March when copepods were not present in the diet or collected in the cores,

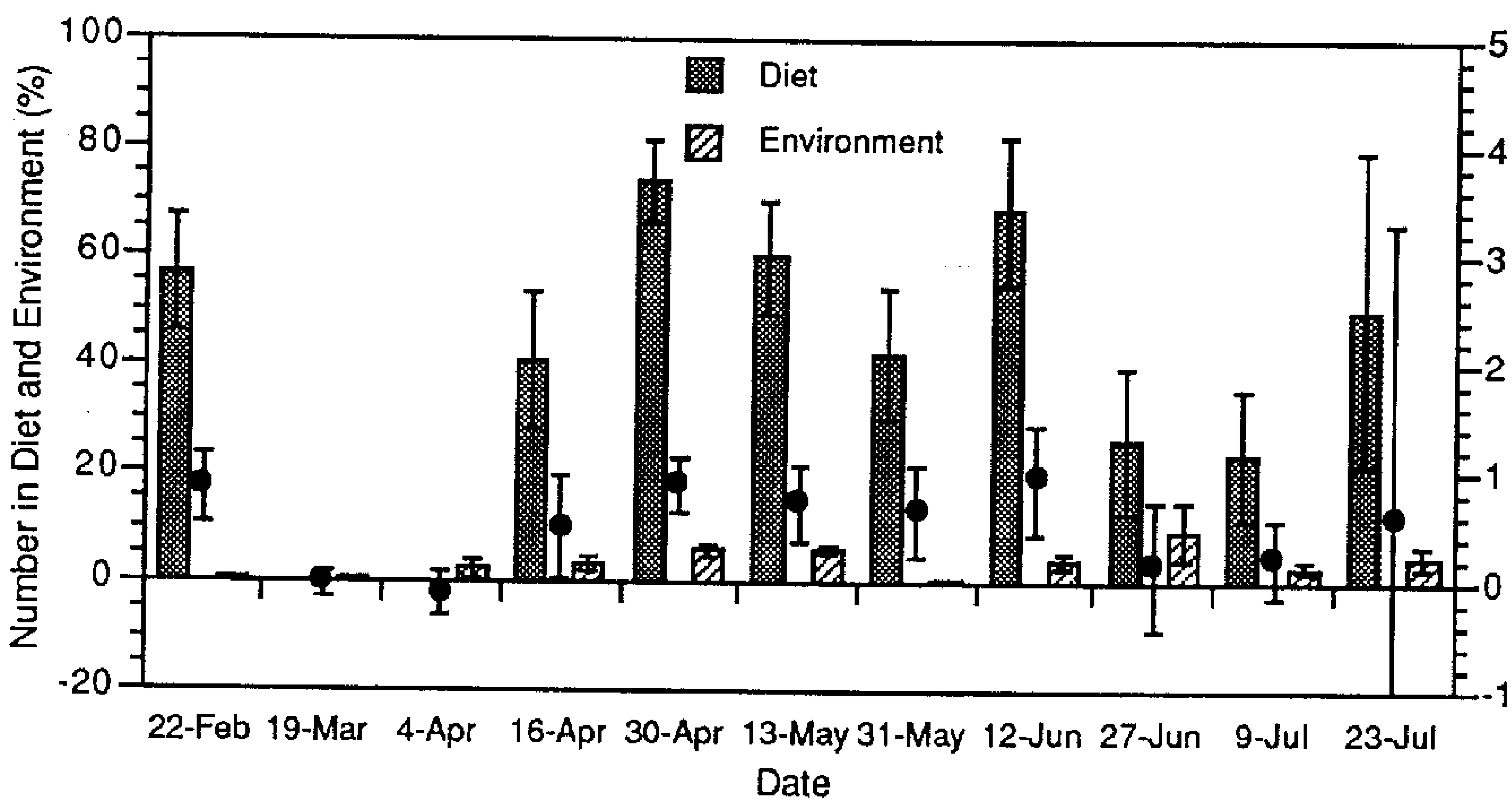

Figure 2.06. Bars represent the mean percentage (± 1 standard error) of copepods in the diet and environment (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

and in late June and July when the 95 % confidence intervals were large was greater because of fewer samples with pinfish present.

Annelids were abundant in the environment but did not occur with a similar frequency in the diet, and this resulted in a significant negative selection on 9 of the 11 sampling dates (Figure 2.07). Mean percent of annelids ranged from 0 to 33 % in the diet and 76 to 92 % in the environment. Even when annelids were greater than or equal to 30 % of the diet, as seen on three separate dates, mean MLIs were still not positive.

Many of the copepods in the diet of pinfish were planktonic calanoids. The core sampling technique is not an adequate method to estimate densities of planktonic prey, and therefore, the modified linear index was also calculated with copepods removed from diet and environment. When copepods were removed from the calculations, there was an increase in the mean percentage of annelids in the diet with values ranging from 0 to 100 % (Figure 2.08). Since copepods had such a low occurrence in the cores, little change occurred in the percent of annelids in the environment, and the mean percent ranged from 78 to 91 %. The MLI with

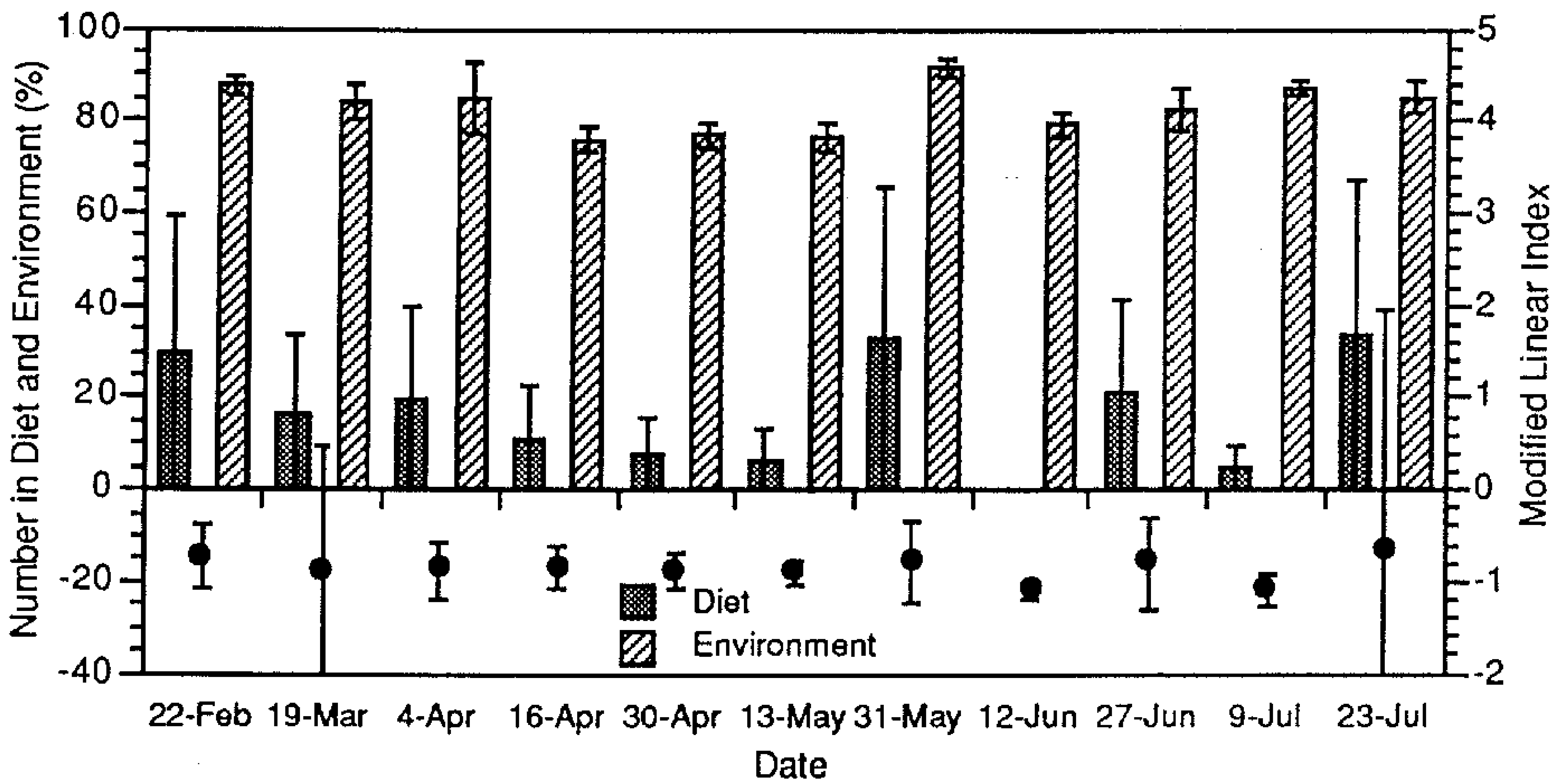

Figure 2.07. Bars represent the mean percentage (± 1 standard error) of annelids in the diet and environment (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

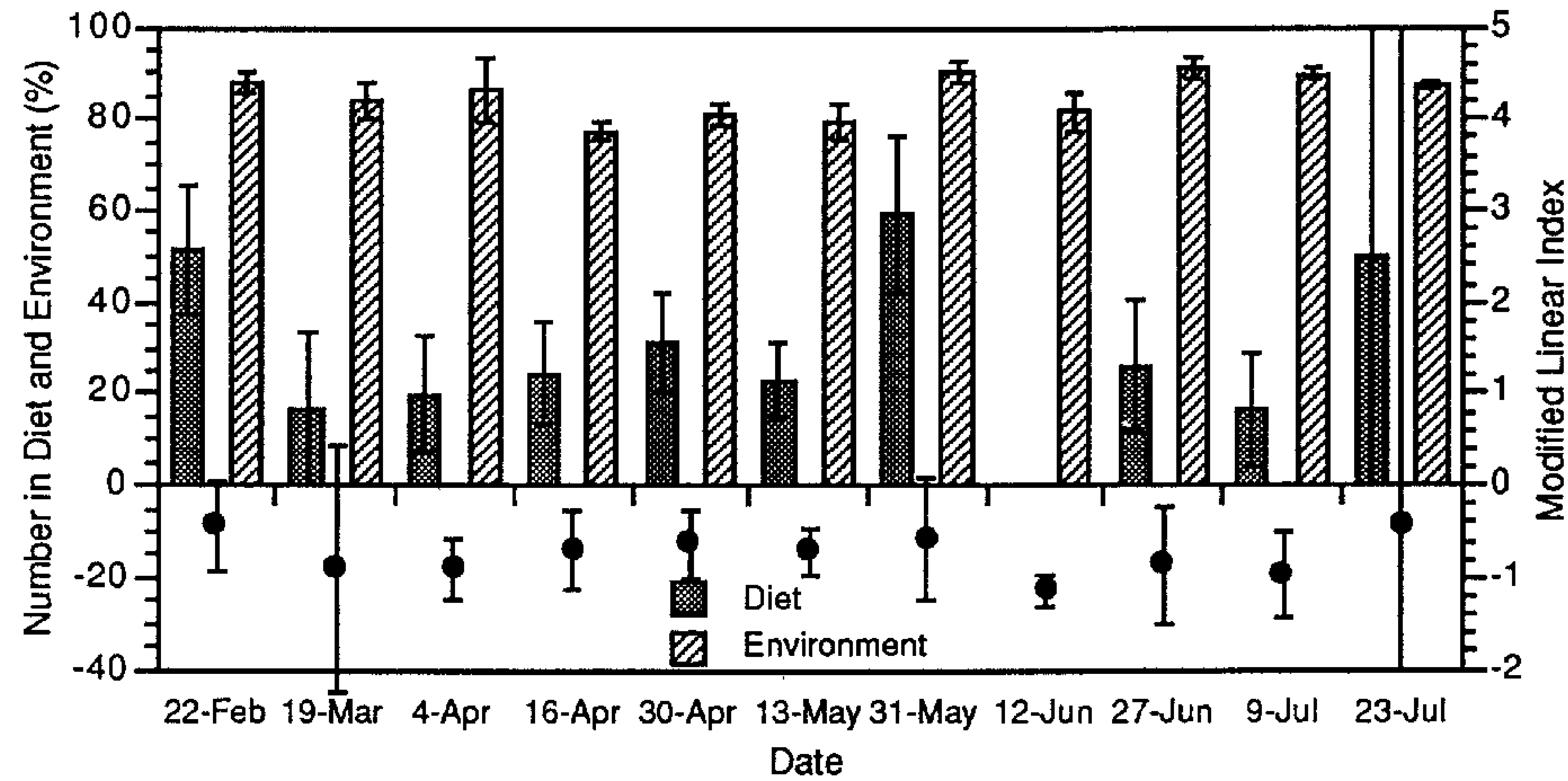

Figure 2.08. Bars represent the mean percentage (± 1 standard error) of annelids in the diet and environment with copepods removed (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

copepods removed was less but similar to the MLI with copepods, and annelids were significantly avoided on 7 of the 11 sampling dates.

For a select group of crustacean prey (including amphipods, tanaids, caridean shrimp and penaeid shrimp), prey selection was examined in greater detail. As with annelids, selection for these crustacean prey was examined with all available prey and with copepods removed from the analysis. In addition, relative selection for these prey was also examined in relation to each other; that is, only this select group was included in the analysis.

Among these crustacea, amphipods were the most abundant in the stomach contents of pinfish and were found in the diet on all but the last sample date. When all available prey were examined, the mean percentage of amphipods in the diet ranged from 0 to 31 % (Figure 2.09). Mean percentages in the environment were much lower ranging from 1 to 8 %. Mean MLIs were generally positive but not significantly different from zero. When copepods were removed from the analysis, the mean percent of amphipods in the diet increased and ranged from 0 to 60 % (Figure 2.10). Mean percent of amphipods in the environment was not affected as much and

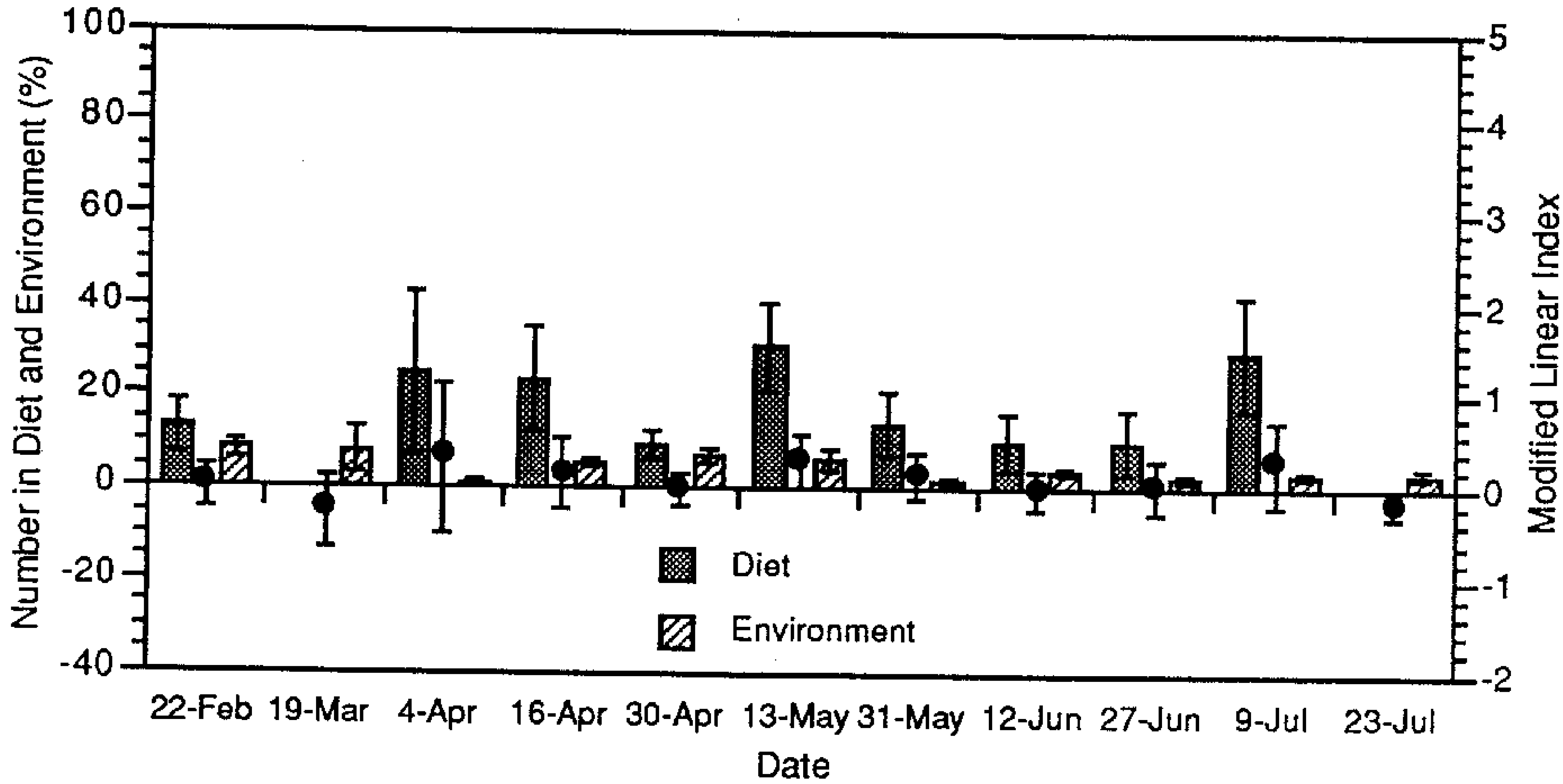

Figure 2.09. Bars represent the mean percentage (± 1 standard error) of amphipods in the diet and environment (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

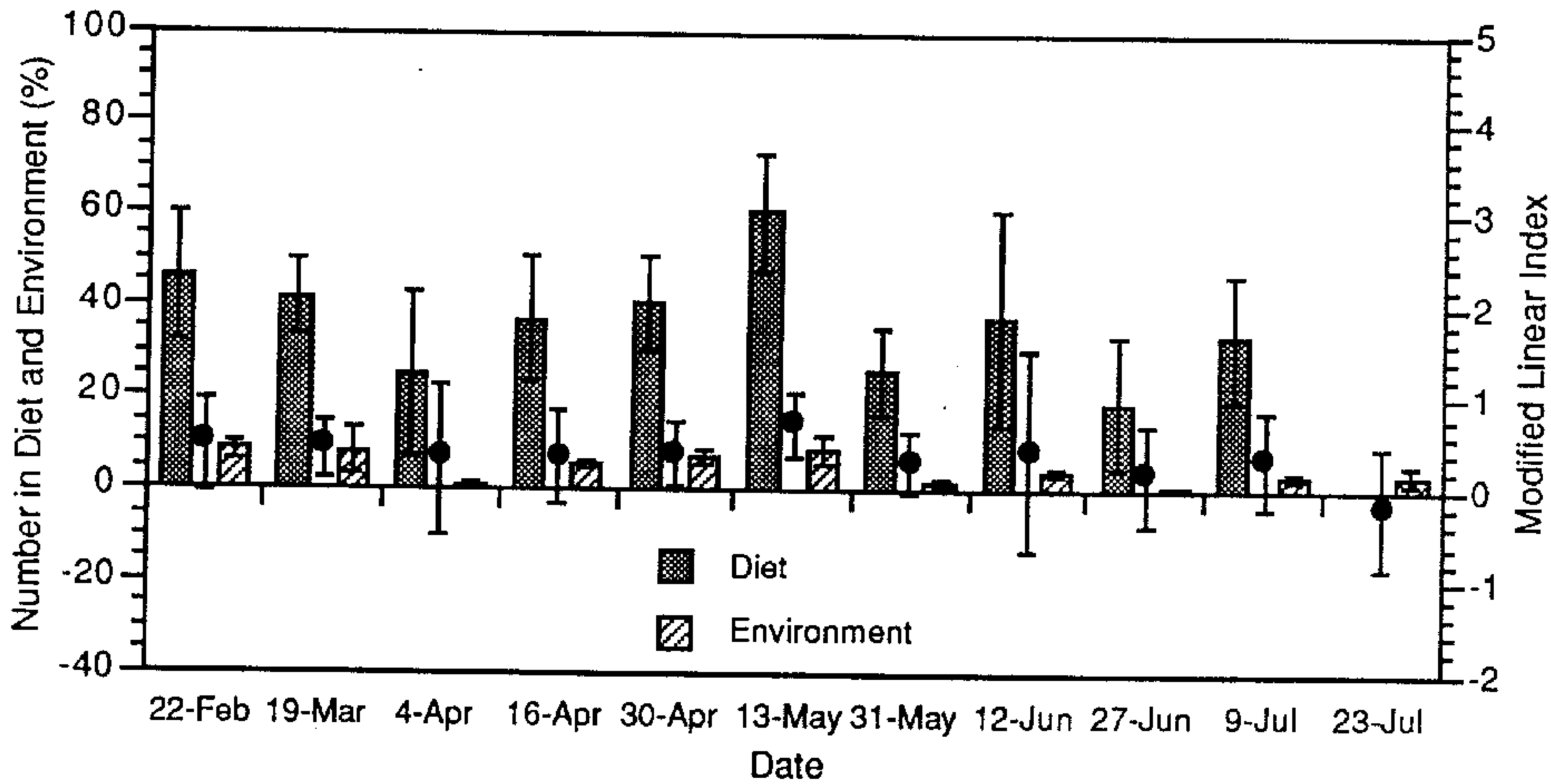

Figure 2.10. Bars represent the mean percentage (± 1 standard error) of amphipods in the diet and environment with copepods removed (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

ranged from 1 to 8 % with a very small increase on some dates. Mean MLIs increased and were significantly different from zero in February and March and in late April and May. Among the four crustacean groups examined, mean percent of amphipods ranged from 38 to 100 % in the diet (Figure 2.11). In addition, amphipods were the most abundant of the select crustacean group in the environment, with mean percent ranging from 12 to 90 %. The mean MLIs were mostly positive during the spring, but were variable and not significantly different from zero. In June and July, the MLIs were near zero or below it.

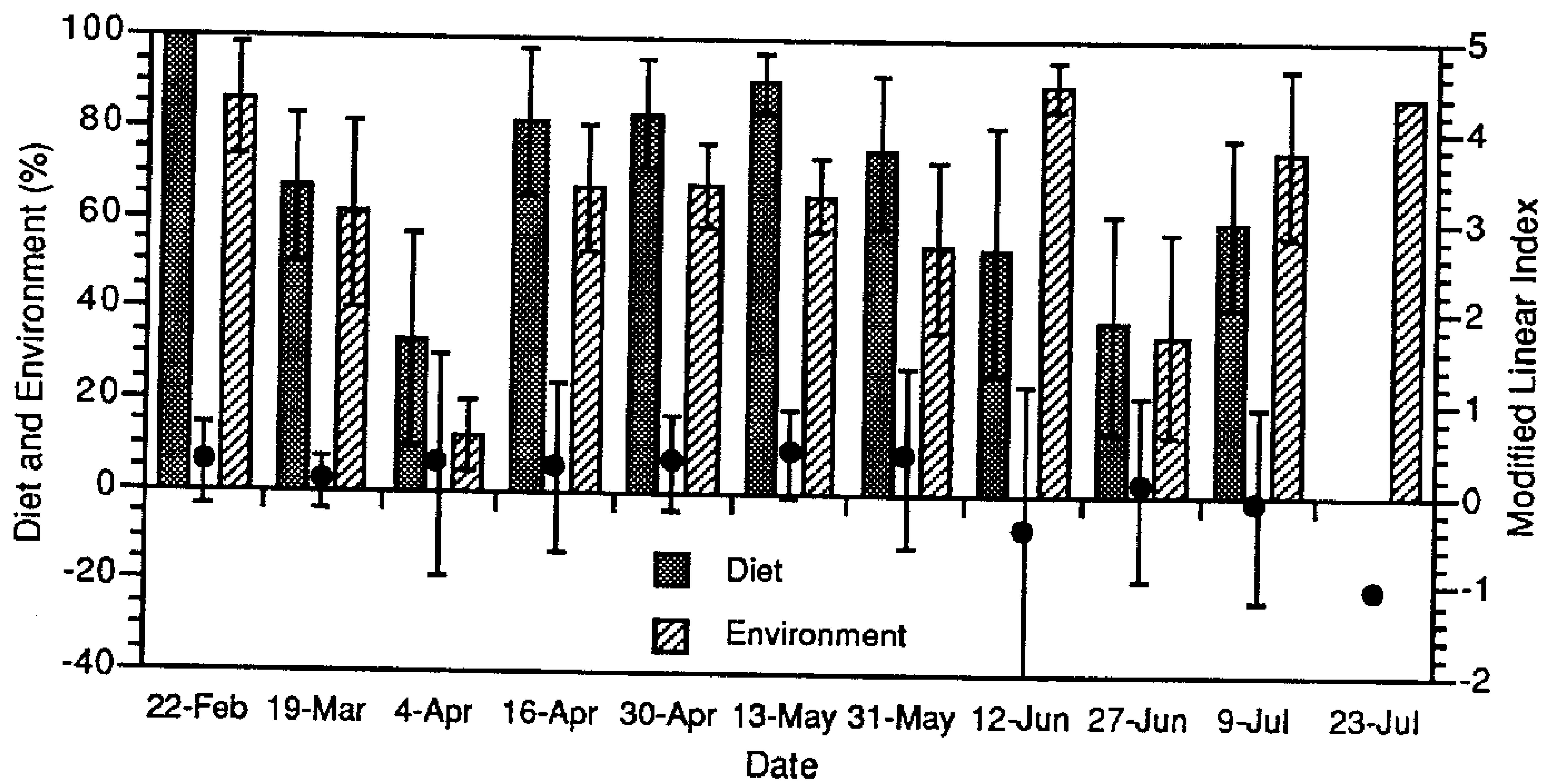

Figure 2.11. Bars represent the mean percentage (± 1 standard error) of amphipods in the diet and environment among selected crustaceans (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

Tanaids occurred in the diet mostly in March and April and had a mean percent ranging from 0 to 30 % (Figure 2.12). Tanaids had low occurrence in the environment compared to all available prey with mean percent never greater than 5 %. However, when tanaids occurred in the diet they were positively selected, but not significantly. Mean percent in the diet and mean MLI of tanaids were mostly affected when calculated with copepods removed (Figure 2.13), particularly on 12 June, when mean percent in the diet increased and mean MLI was significantly positive. The mean MLI was also positive during March and early April, but not significant. When only the select crustacean group was considered, tanaids had higher mean percents in the diet and environment ranging from lows of 0 to highs of 42 and 62 % (Figure 2.14). On several dates the mean MLI was negative, two were significantly different from 0. Mean MLI was only positive on 12 June, but was not significant.

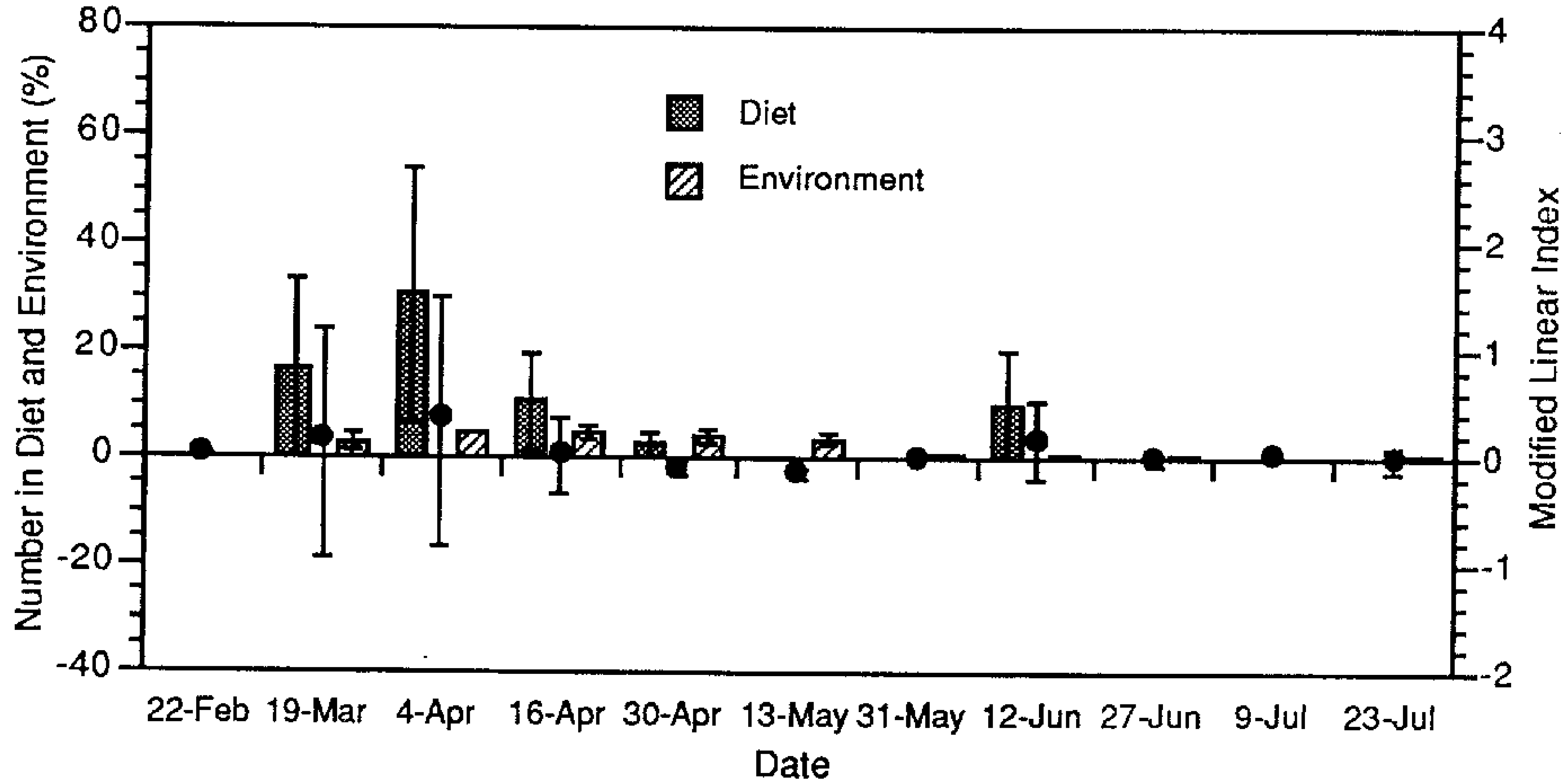

Figure 2.12 Bars represent the mean percentage (± 1 standard error) of tanaids in the diet and environment (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

Penaeid shrimp occurred in the diet on 5 sampling dates, mean percent ranged from 0 to 17 % in the diet and was never greater than 0.1 % in the environment when all prey were used in the analysis (Figure 2.15). The mean MLI was positive only when penaeid shrimp were eaten; however, mean MLIs were not significantly different from zero. Removal of copepods from the analysis had negligible affect on mean percent in the environment (Figure 2.16). However, mean percent in the diet increased to a high of 50 %. Mean MLIs also increased and had more variability, and were always positive when penaeid shrimp were eaten. When compared to the select crustacean group, increases in means of percent in diet and

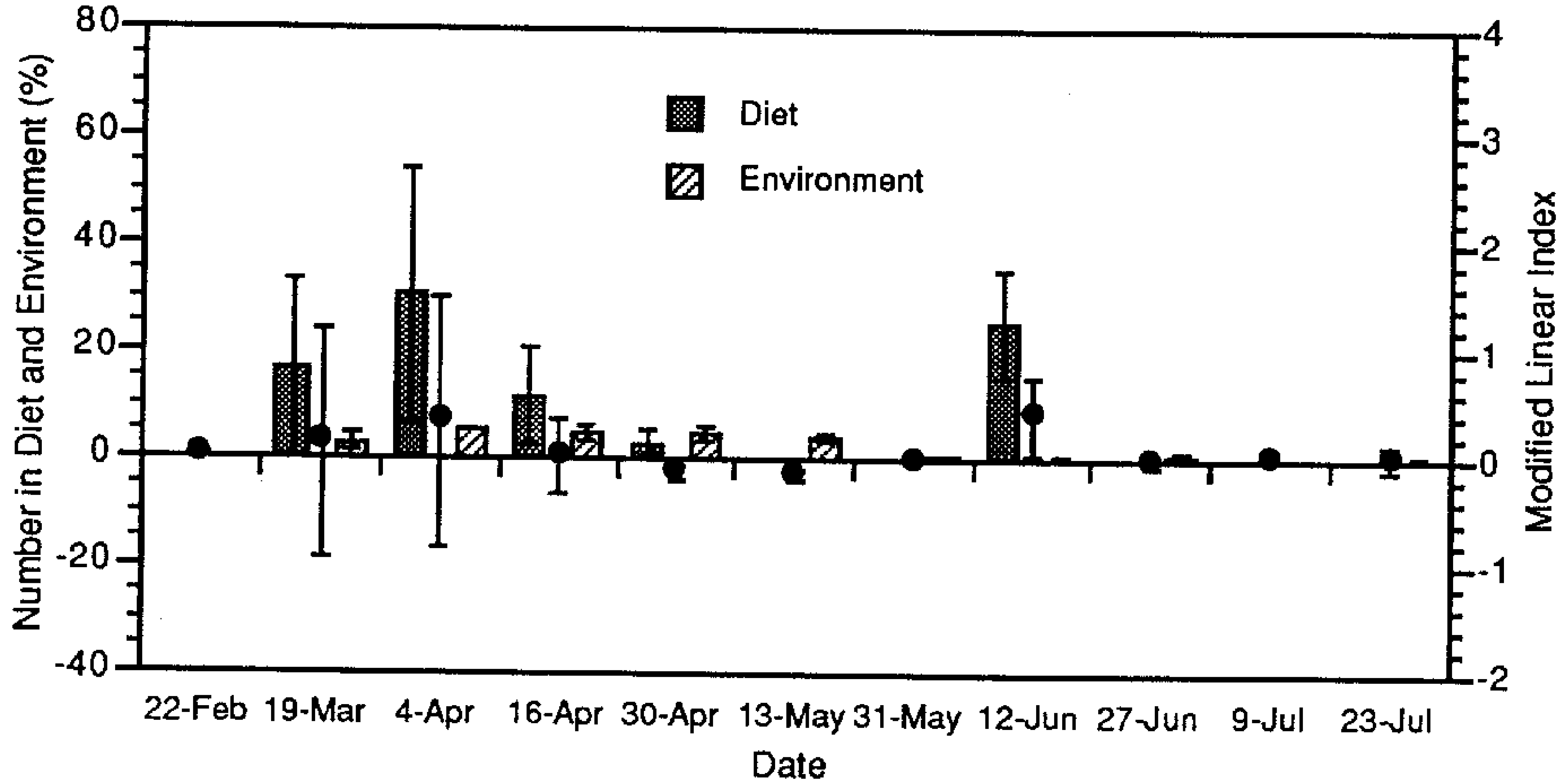

Figure 2.13 Bars represent the mean percentage (± 1 standard error) of tanaids in the diet and environment with copepods removed (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

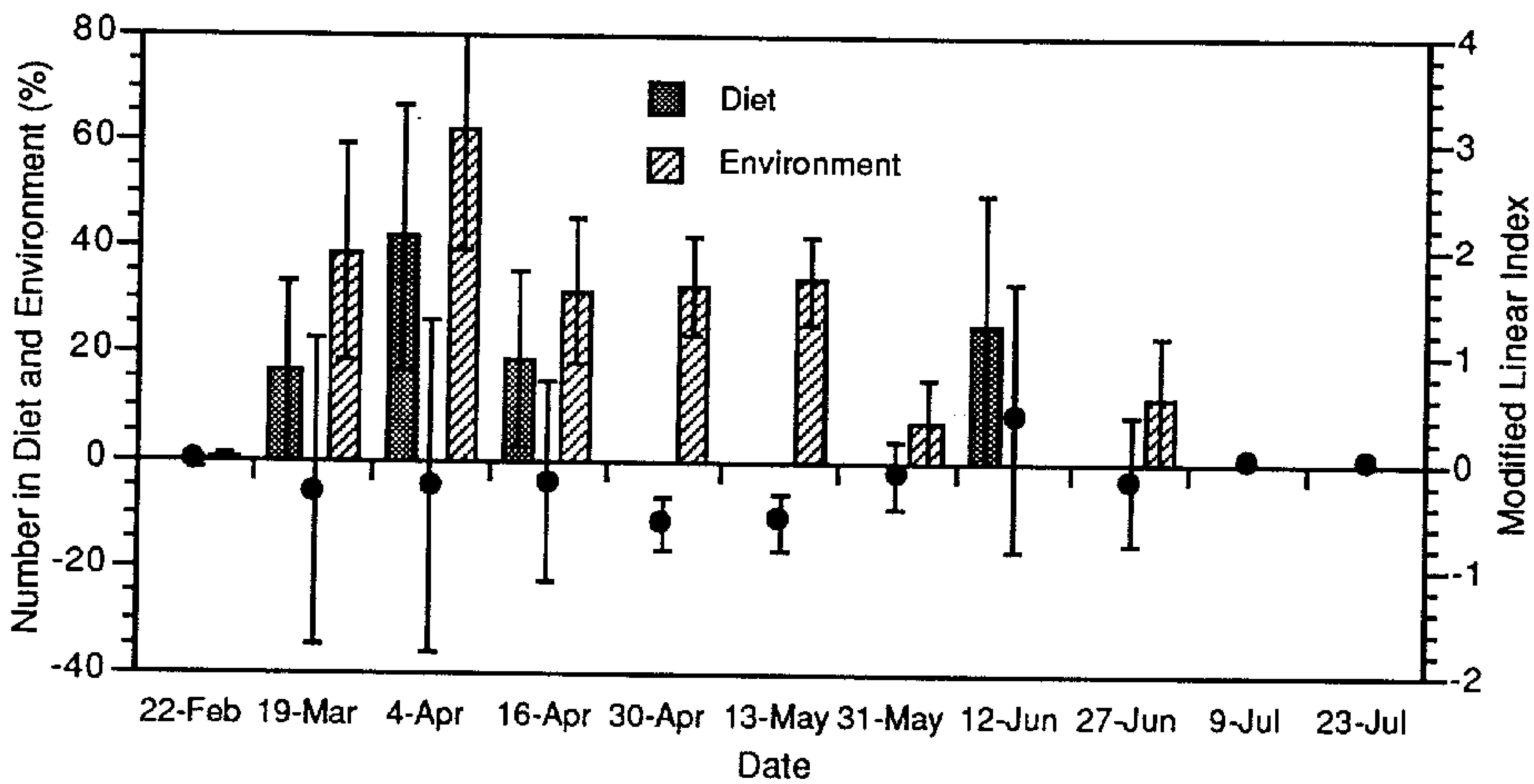

Figure 2.14. Bars represent the mean percentage (± 1 standard error) of tanaids in the diet and environment among selected crustaceans (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

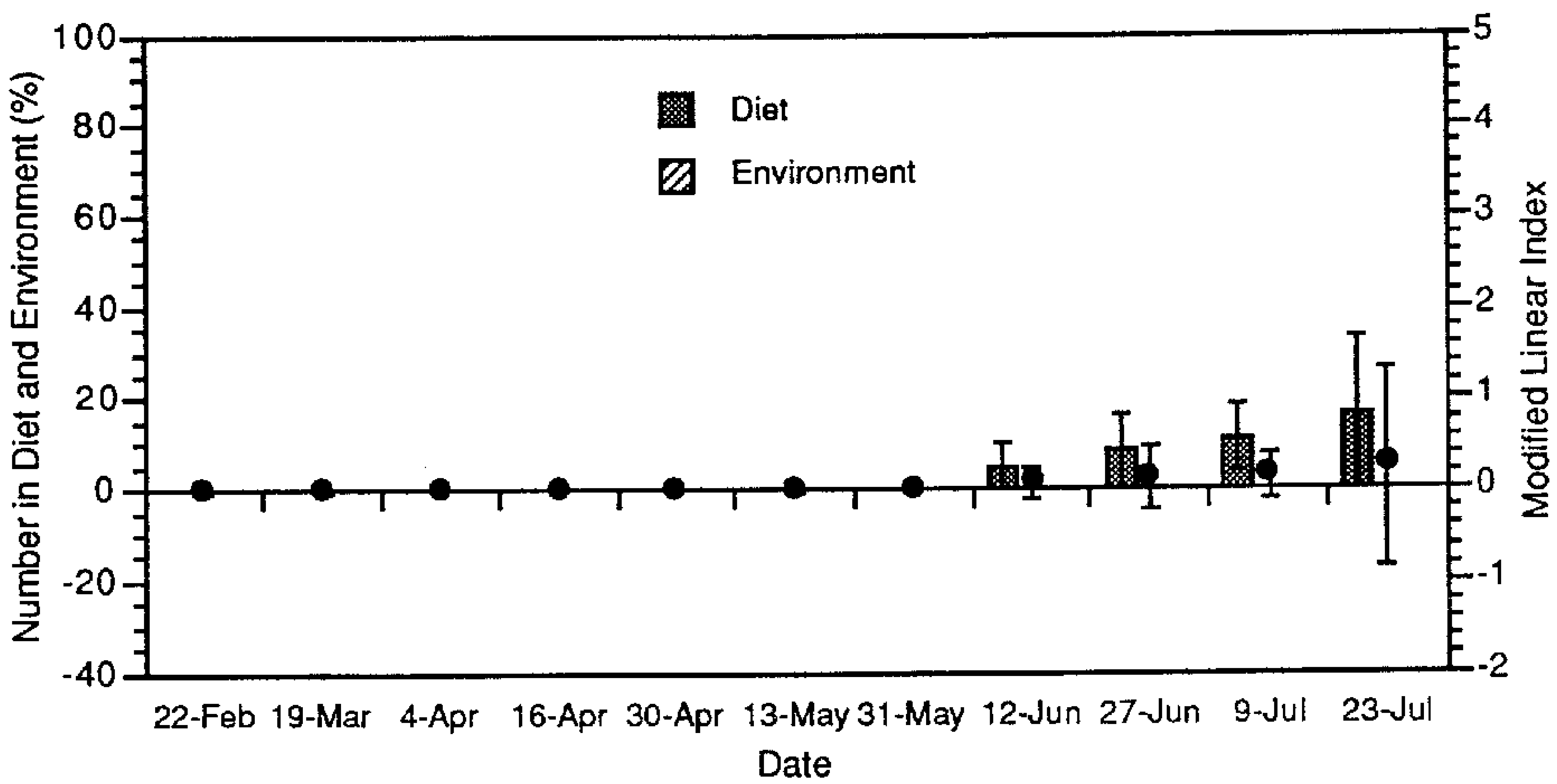

Figure 2.15. Bars represent the mean percentage (± 1 standard error) of penaeid shrimp in the diet and environment (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

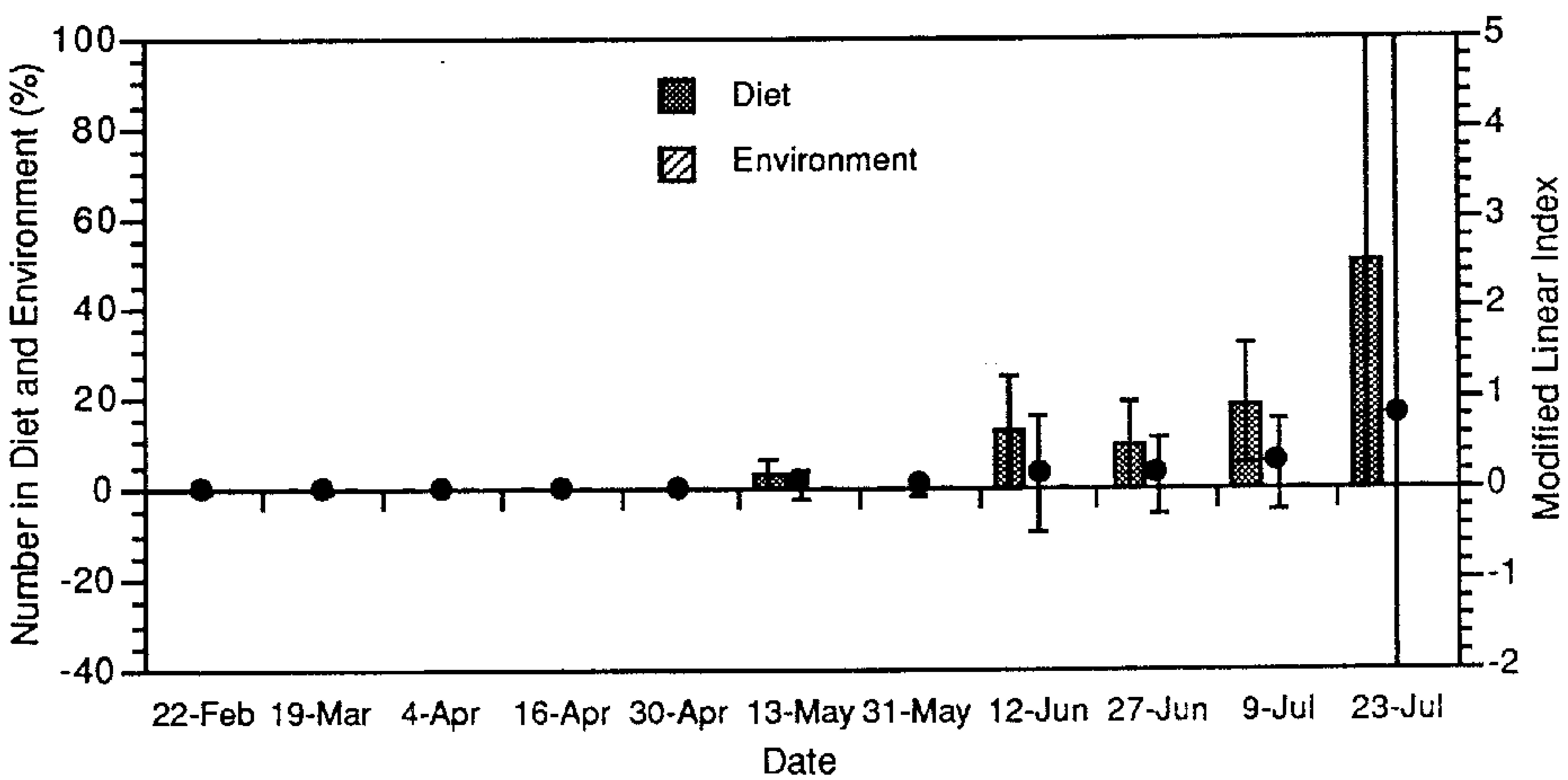

Figure 2.16. Bars represent the mean percentage (± 1 standard error) of penaeid shrimp in the diet and environment with copepods removed (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

environment occurred with ranges from 0 to 100 % and 0.1 to 22 % (Figure 2.17). Mean MLI became negative on some sampling dates when shrimp were not eaten, but overall the mean MLIs were not significantly different from zero.

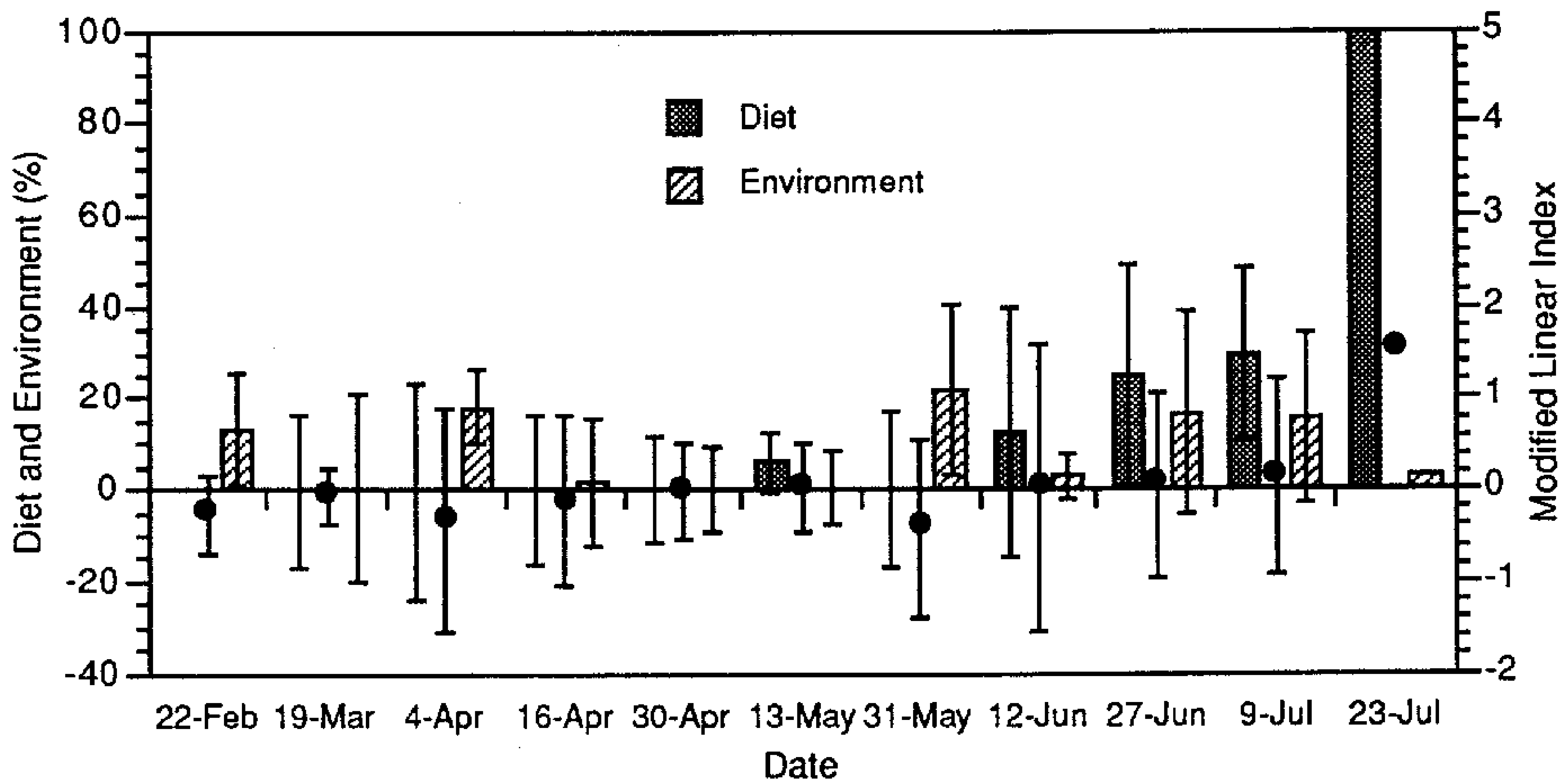

Figure 2.17. Bars represent the mean percentage (± 1 standard error) of penaeid shrimp in the diet and environment among selected crustaceans (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

Caridean shrimp were eaten on 7 of the 11 sampling dates with greatest percent in the diet occurring on 4 April (Figure 2.18). A low mean percentage in the environment resulted in positive mean MLIs when caridean shrimp were eaten, but they were not significantly different from zero. The removal of copepods from the analysis had little affect on mean percent in the environment or mean MLI of caridean shrimp, but the percent increased slightly in the diet, particularly during May and early June (Figure 2.19). Increases in both mean percent diet and environment occurred when analysis was run with the select crustacean group (Figure 2.20); these means ranged from 0 to 38 % and 0 to 37 %. Mean MLIs were greater when caridean shrimp were eaten, but they were more variable and not significantly different from zero.

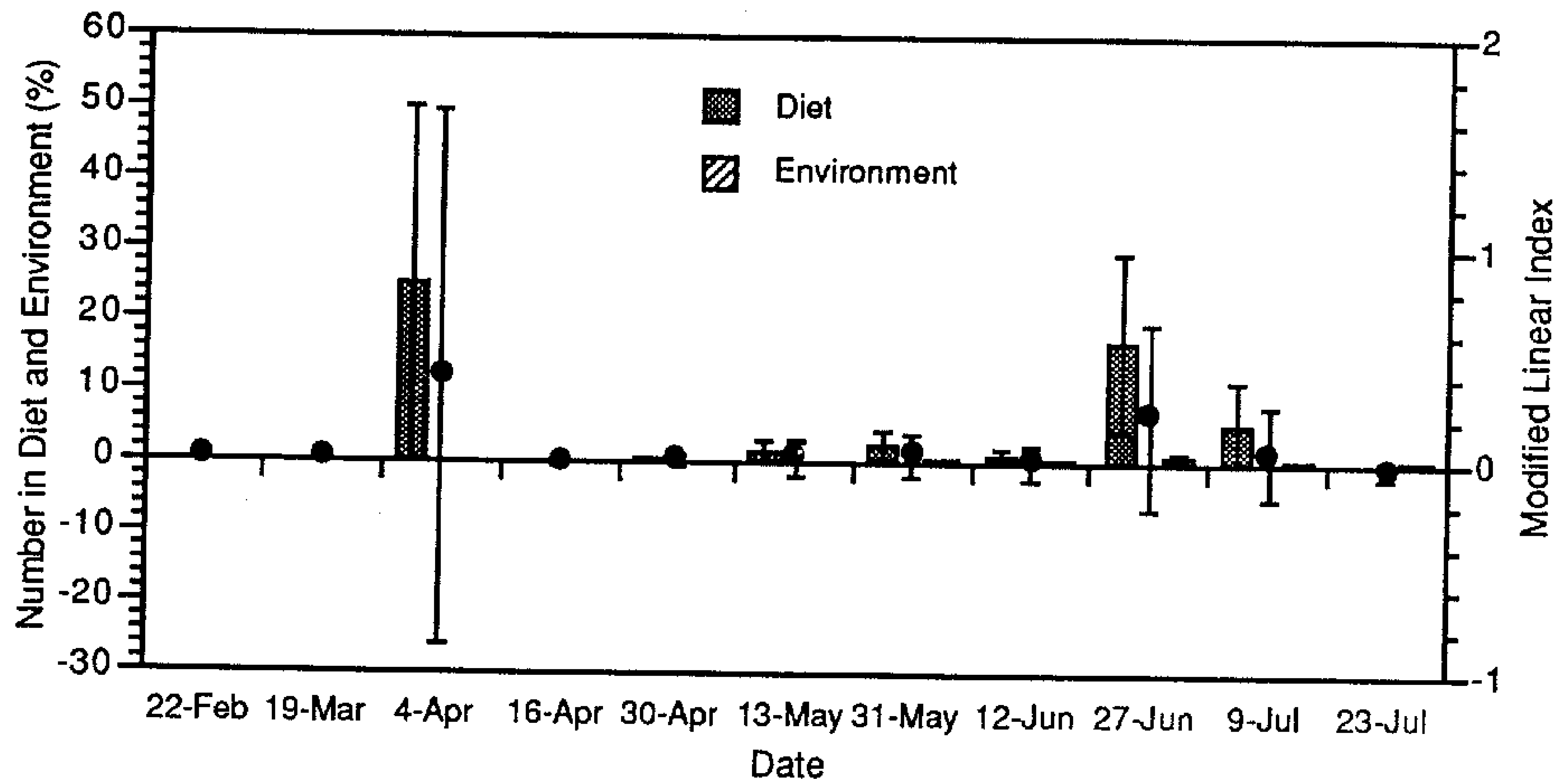

Figure 2.18. Bars represent the mean percentage (± 1 standard error) of caridean shrimp in the diet and environment (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

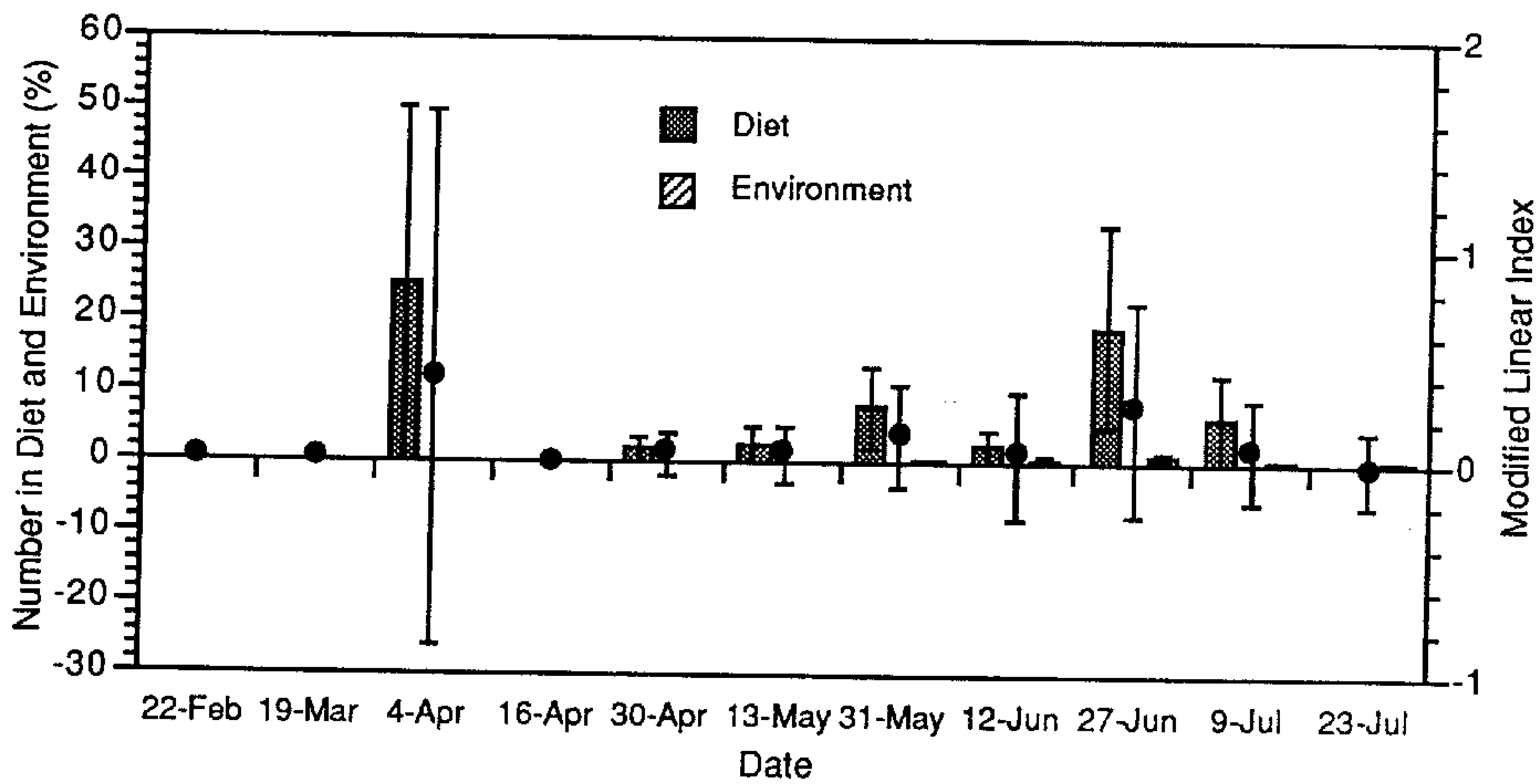

Figure 2.19. Bars represent the mean percentage (± 1 standard error) of caridean shrimp in the diet and environment with copepods removed (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

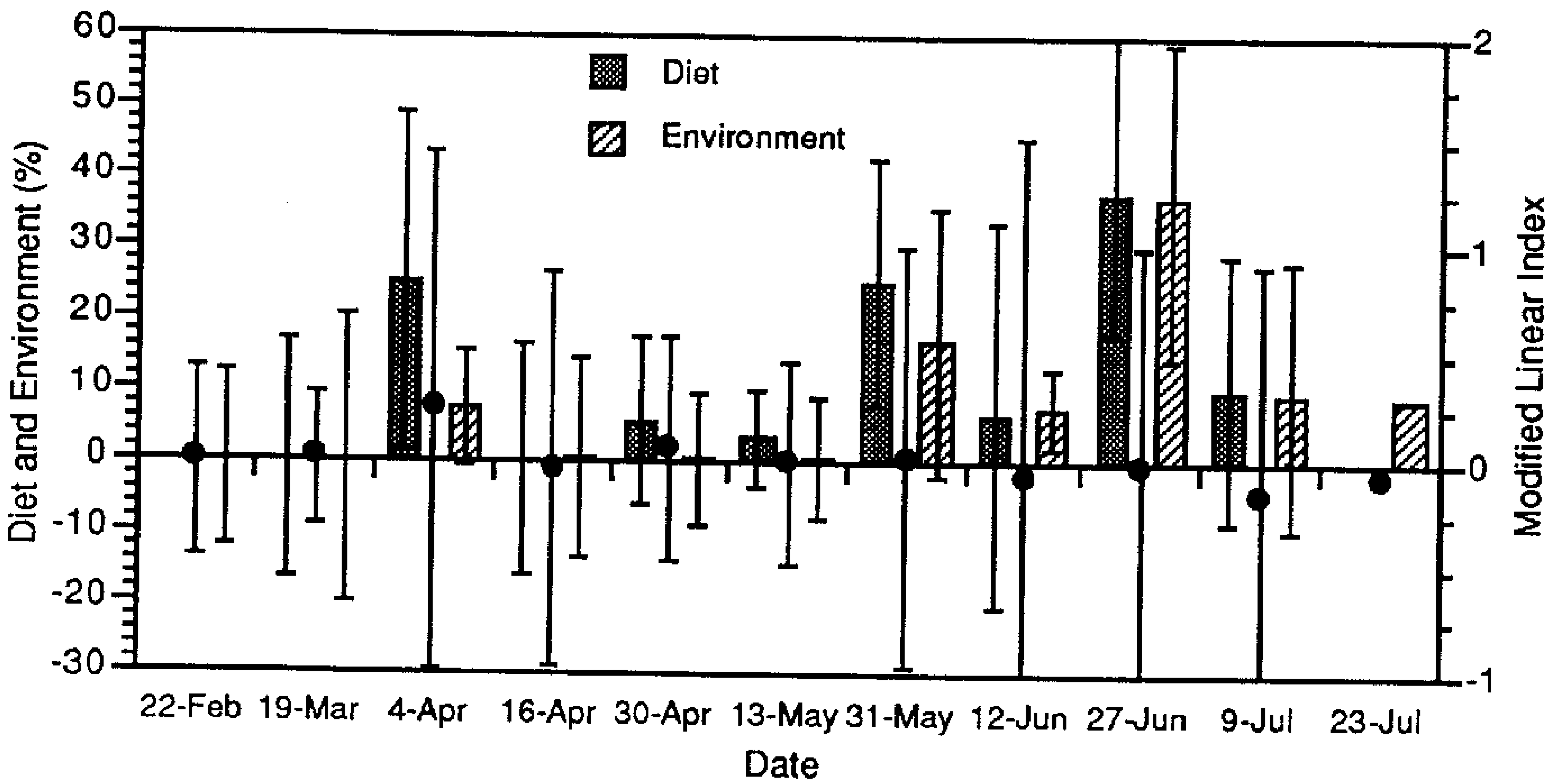

Figure 2.20. Bars represent the mean percentage (± 1 standard error) of caridean shrimp in the diet and environment among selected crustaceans (untransformed data). The mean (●) modified linear index is also shown with 95% confidence limits.

DISCUSSION

Important prey in the diet of fishes were determined on the basis of both number and weight. By weight, pinfish diets consisted overall of about one-half plant material and one-half animal matter. The relative percentage of these components, however, shifted over the sampling period from a diet dominated by animals in early spring to a diet high in plant material in late spring and early summer. Within the animal component of the diet, copepods were an important prey item by number, but their contribution to the diet by weight was reduced considerably. On the basis of both numbers and weight, other prey that appeared important in the diet during some portion of the sampling period included annelids, tanaids, amphipods and shrimp.

A determination of the importance of any prey in the diet of a predator should also include an assessment of prey availability. Selection of a prey item despite low availability in the environment can be used as an indicator of prey importance. Although prey accessibility is difficult to determine, prey density can be determined. Often estimates of prey density are variable and inconsistent with location of predators. The drop sampling technique, however, provided consistent densities with measurable variability for all but the copepod prey. The drop sample also provided the density of prey along with the density of the predator in the immediate vicinity of feeding.

The importance of plant material in the diet of pinfish shifted dramatically over the sampling period. As the season progressed, the proportion of plant material in the diet of pinfish increased. This dietary shift coincided with growth of pinfish from small juveniles to subadults. Trophic ontogeny in pinfish was reported in studies by Carr and Adams (1973) and Stoner (1980). Carr and Adams (1973) identified five trophic stages of pinfish from Crystal River, FL, progressing from planktivory to herbivory to carnivory. Similar trophic stages were recognized by Stoner (1980) for pinfish from Appalachee Bay, FL, however the largest pinfish (>120 mm SL) were herbivorous. In support of the change to herbivory, Stoner (1980) showed the tooth morphology changed from biting incisors in carnivorous stages to grinding molar teeth in large pinfish.

Stomach contents of pinfish in my study were generally similar to those in Carr and Adams (1973) and Stoner (1980). The dietary shift in pinfish through the spring with an increase in plant consumption, however, also coincided with a change in the available prey. The density of the animal prey declined substantially over the sampling period. Both Carr and Adams (1973) and Stoner (1980) examined their fish in 5 mm size categories and combined stomach contents over the sampling period without regard to changes in prey densities. I examined individual fish on each sampling date to allow for grouping in size categories if necessary. A comparison of the animal and plant components of the diet for different size classes indicated that prey densities affected the amount of plant material consumed. During a period of high prey density there was no strong trend towards increased herbivory with size(Figure 2.21). During a period of low prey density, the amount of plant material in the diet increased for each size category, but this increase was not as dramatic as shown in Figure 2.21. Comparison within sizes showed increased plant material in the diet with decreased animal

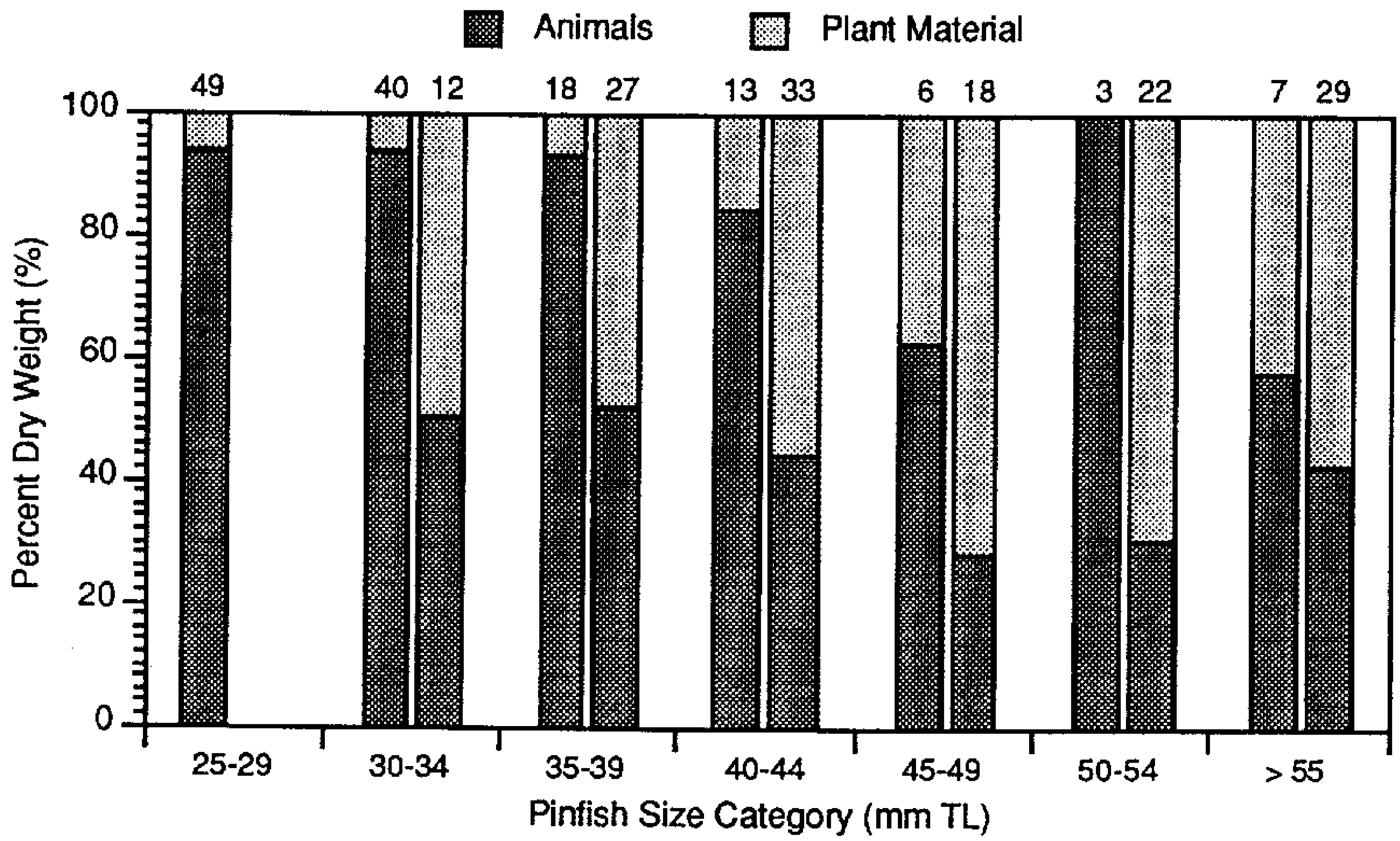

Figure 2.21. Comparison of the animal versus plant component of the diet for 5 mm size categories of pinfish during different periods of animal prey densities. In each size category, the first column represents a period of high prey density (16 April to 13 May), and the second column represents a period of low prey density (31 May to 23 July). Values at top of each column are the number of fish with food in each size category.

densities. This can also be seen in Figure 2.22; as select crustacean prey groups declined in density more plant material was consumed. This relationship between densities of select crustacean prey groups and the amount of plant material ingested was negative and significantly correlated (r=-0.65, n=11, p=0.03).

Thus, an alternative hypothesis for the dietary shift in pinfish through the spring is that preferred animal foods become scarce by late spring as pinfish get larger, and the dietary shift is related to this decline in animal prey. Reduced prey availability may cause pinfish to strike at potential prey on seagrass blades with limited success resulting in the incidental ingestion of seagrass. Caldwell (1957) was probably the first to recognize this behavior by suggesting plant content of pinfish stomachs was probably incidental to their diet. In addition, laboratory studies conducted by Main (1985) and Luczkovich (1988) suggest the incidental intake of plant material while pinfish attempt to obtain animal prey.

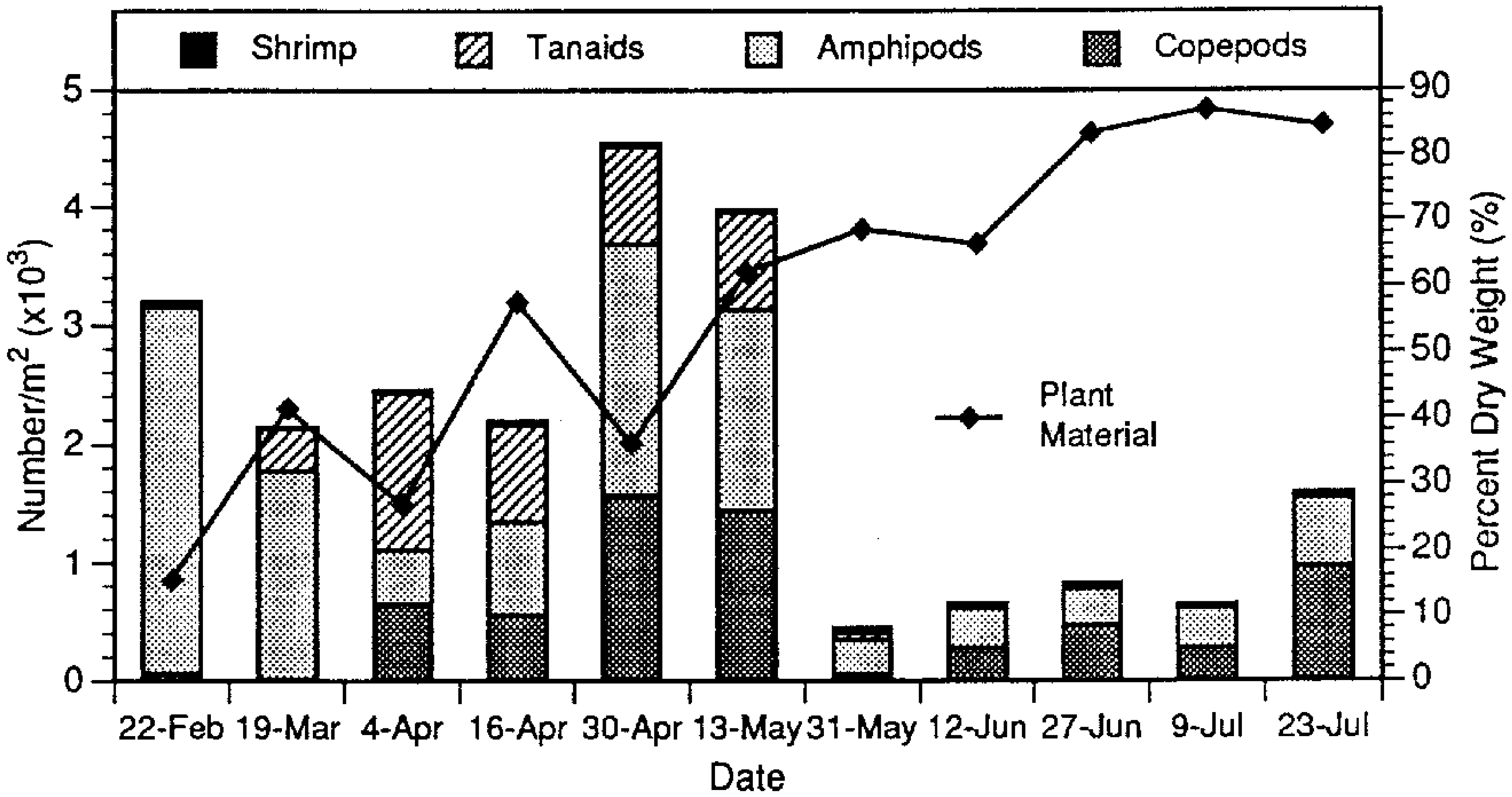

Figure 2.22. Select crustacean group densities (stacked bars) are compared to mean percent plant material in dry weight consumed by pinfish (line with ◆).

Other circumstantial evidence also suggests that any shift to a herbivorous diet in adults may be of necessity and not of choice. Physiologically, cellulase enzymes are required within the intestinal tract to digest plant matter allowing for the plant carbon to be available to the organism for assimilation. Stickney and Shumway (1974) found no evidence of cellulase activity in pinfish, and Weinstein *et al.* (1982) only found traces of cellulase activity. Also, intestinal tracts of herbivorous fish are typically long and often coiled to allow more processing time for the hard-to-digest plant matter, while carnivorous fish have short straight intestines allowing for rapid processing of easily digested animals (Balon 1986). The pinfish digestive tract is consistent with the carnivorous fish with virtually only a V-shaped stomach and relatively short intestine. In addition, most of the plant material in pinfish stomachs was not broken down; short pieces of the *H. wrightii* blades were often counted during the stomach analysis. The voracious feeding behavior of pinfish does not correspond to the more docile, slow-moving behavior of herbivorous fish (Hoese and Moore 1977). Pinfish nip at substrates and animals as they feed (Thomas 1989). Short pieces of seagrass blades in the stomachs may have been the result of missed strikes at epifaunal prey. Finally, as pinfish grow larger and mature, they move to the nearshore and offshore waters of the Gulf of Mexico. Adult pinfish in the offshore environment contain bivalves and crustaceans (Darnell 1983). In order to support a large population of herbivorous adult pinfish, abundant macrophytes would be necessary in the offshore environment. No expansive areas of macrophyte beds exist in the offshore area of Texas.

Within the animal component of the diet, Strauss's linear index was modified and used to assess prey selection. The MLI was useful because it had a normal distribution and statistically detected differences in selection and avoidance from random feeding with confidence intervals. The MLI relies heavily on good estimates of prey availability in the vicinity of the predator. Adjusting the MLI by removing certain prey groups from the calculation allows the ability to better discern trends among different prey groups.

In the selection analysis, most of the crustacean animal prey were positively selected although not always significantly, and annelid prey were significantly avoided. Different prey items may be used to determine MLIs. Leaving one or more prey out of determining the selection index dramatically affects the value of the MLI. Determining which prey to use in the MLI was important because different results are obtained from the inclusion of all to exclusion of only a few. Copepods were strongly preferred; but calanoids were inadequately sampled in the environment and may have biased this selection. Annelids were avoided both with and without copepods in determining MLIs. To discern differences which may be masked by the dominant effects of annelids, a select group of crustaceans were considered in determining a MLI. Among the select group, amphipods were positively selected on most sampling dates and tanaids were mostly consumed at random. In the late spring and early summer the larger crustacean prey, caridean and penaeid shrimps, were positively selected but not significantly from random feeding. However, less fish available for analysis at this time reduced the power of detecting selection from random feeding.

Although relatively little data were available on the diet of southern flounder, amphipods brown shrimp and fish were important food items. As southern flounder increased in size, larger prey, shrimp and fish, contributed more to the diet. Other studies found southern flounder consumed shrimp and fish, but most of these fish were greater than 100 mm TL (Compare Table 2.01). Stokes (1977) found mysids, shrimp and amphipods in the 10-150 mm TL southern flounder. Studies involving selection of prey by southern flounder do not exist. Prey selection could not be completed in this study because of the lack of available prey densities and the paucity of southern flounder in samples from Christmas Bay.

CHAPTER III

LABORATORY EXPERIMENTS ON PREY SELECTION BY PINFISH AND SOUTHERN FLOUNDER

INTRODUCTION

Prey selection by fish under natural conditions is affected by prey size. In any study of prey species selection, therefore, it is important to have information on optimal sizes to prevent the misinterpretation of results. In order to separate these effects, laboratory studies can control the size of available prey accessible to the predator and be used examine size selection. The effect of prey size on predation has been extensively studied in freshwater systems (review in Nilsson 1978; Zaret 1980), and fish predators feeding on individual prey generally have a prey size range constrained by their gape (O'Brien 1987), or throat width (Werner 1979). Optimal prey size tends to increase with an increase in fish body size (Werner 1979; O'Brien 1987). If all prey sizes available can be eaten, the general tendency in fishes is to take the largest available prey.

The predators examined in this study, pinfish and southern flounder, appear to feed on a wide range of prey sizes. Pinfish have been shown to feed on prey ranging in size from a few millimeters (Nelson 1979) to prey of a size equal to their own length (Main 1985). In the laboratory, Minello and Zimmerman (1983) reported pinfish feeding on very large penaeid shrimp. Larger juvenile southern flounder (90-120 mm TL) feed on prey from 17 to 43 % of their length (Minello *et al.* 1989b).

The first experiments in this section were designed to examine size selection by juvenile pinfish and southern flounder. An analysis of size selection from field data was also collected. Finally, selection for prey species was examined in separate experiments with pinfish and southern flounder feeding on amphipods, grass shrimp or brown shrimp.

MATERIAL AND METHODS

Field Observations

Size selection was examined in pinfish collected from Christmas Bay through an analysis of the sizes of prey eaten and their availability during the spring 1986. When possible, infauna and epifauna crustacea and fish prey that occurred in the stomach contents of fish examined were measured for total length. For prey eaten, prey size was converted to a percentage of the fish size. A total of 102 pinfish consumed measurable prey and were used in this analysis, but only one southern flounder was collected during spring 1986. Other southern flounder examined were collected in spring 1985 (see Chapter 2).

Laboratory Experiments

Individual fish (pinfish and southern flounder) were tested in 6.6 L cylindrical containers (29.7 cm diameter, 30 cm height). Filtered seawater was used in the containers with salinities of 25 to 30 ‰ and a temperature of 25° C. Usually eight replicates with predators were run at one time with two controls containing prey only. Water in containers was aerated prior to experiments and dissolved oxygen was always above 6 ppm in containers examined. To minimize any effects caused by oxygen depletion, experiments were never run for more than 6 hours.

Pinfish and southern flounder were collected with an otter trawl from nearby estuarine areas, and tow times were kept below 3 minutes to prevent stress or damage to the fish. Prior to experiments, fish were maintained in closed system aquaria in a room with ambient temperature, controlled at 25°C. Salinity in the aquaria was maintained at 25 ‰. Lighting was provided by a window in the laboratory. Experimental fish were fed invertebrates (shrimp, crabs, amphipods, insects, etc.) and small fishes of a variety of sizes that were dip-netted from shoreline habitats in Galveston Bay. Fishes were maintained up to three weeks prior to an experiment, but generally they were used in an experiment within 5 days of capture. Fish were used only once in experiments, except for one group of flounder (8 in number) which were used in a second experiment after being held for 9 days between experimental runs. Shrimp prey were obtained by dip-netting from local shallow ponds and bayous on the day of the experiment.

Predators and prey were placed in the experimental chamber for twenty-four hours to allow acclimation to experimental conditions. Fish were not fed for this period to control their state of hunger. Depending on the number of prey, either the predator or prey were kept in a cage during the acclimation period. The cage was a 15 cm diameter PVC cylinder flush with the bottom, covered with 1.0x1.5 mm mesh on the top and weighted down with lead weights. Lighting was provided by overhead fluorescent daylight bulbs on a 12:12 L:D cycle. Following the acclimation period, the cage was removed by tongs, the chamber was topped off with water and a transparent lid sealed the system. The lid prevented escape of any shrimp from the chamber.

A contingency table analysis of Independence (Sokal and Rohlf 1981) was used to determine whether the frequency of prey eaten was significantly different from the expected frequency. Assuming all prey categories are selected equally, the expected outcome is the ratio of the number of prey eaten to the number of prey available within the category.

Size Selection Experiments Penaeid and caridean shrimp were used as prey in size selection experiments because they were available in a relatively large size range. Amphipods were not examined in size selection experiments because of their small size (< 10 mm TL). In the first experimental design, three sizes of either *Palaemonetes pugio* or *Penaeus aztecus* shrimp were available as prey for pinfish or southern flounder. Pinfish ranged in size from 51 to 78 mm TL and southern flounder from 50 to 125 mm TL. Predators in the size range of 30 to 80 mm TL can generally feed on smaller prey efficiently. Effects of prey size were expected near the upper limit of prey sizes generally available. Shrimp prey (both brown shrimp and grass shrimp) used in experiments ranged in size from 10-33 mm TL. In these experiments, prey were characterized as small, medium and large and these categories were distinguished by differences of at least 2 mm TL. Prey sizes for these categories were not fixed among replicates because variability in sizes of both available prey and predators. Mean predator and prey sizes for experiments are shown in Table 3.01. The three shrimp were placed in the PVC cage, and the cage was transferred to the experimental chamber.

Table 3.01. Mean sizes for prey categories and predators used in experiments testing size selection with relative sizes of small, medium and large. All sizes were measured in millimeters total length.

Treatment	Prey Size Category Small	Medium	Large	Fish Size
Pinfish				
Grass shrimp	13.43	18.04	22.64	60.57
Brown shrimp	18.71	22.29	26.07	58.43
Southern flounder				
Grass shrimp	14.00	17.68	21.84	68.58
Brown shrimp	16.08	20.33	25.17	69.83

The observation in these experiments was relative size of the first shrimp eaten. Visual observations were made of the number of prey in the container at approximately 10 minute intervals. When a shrimp was missing and presumed eaten, the remaining shrimp were measured to determine size of the eaten prey. If predators ate more than one shrimp before the initial size selection was observed or if no prey were eaten within a three hour period, the experiment was stopped and no data were recorded.

In the second size selection experiments, 15 shrimp were used as prey in each replicate and fish were allowed to feed on multiple prey. In this design the fish were measured and placed in the PVC cage within the experimental chamber, and the shrimp were added outside the cage. Shrimp sizes ranged from 14 to 33 mm TL with one shrimp available for every 1 size category. Eight replicates were run twice for both pinfish and southern flounder for a total of 16. Treatments with pinfish were run for four hours; southern flounder were allowed to feed for six hours. The size of each shrimp eaten was determined by comparing sizes of shrimp remaining with those initially present.

Species Selection Experiments In prey species selection experiments, individual brown shrimp and grass shrimp prey were available to a single pinfish and southern flounder in each container. Prey shrimp were measured for equal sizes before being used in a container; shrimp ranged from 18 to 22 mm TL. Eight replicates were conducted for each fish predator. Experiments with the southern flounder also included an amphipod, making three prey available to the fish. Amphipods were much smaller than the shrimp prey, ranging between 3 and 6 mm TL.

RESULTS

Field Observations

Crustacean prey were measured when encountered in the stomach contents of fish. Of the available prey in field samples, however, only amphipods and decapod crustaceans were measured. Therefore, only sizes of amphipod and shrimp prey were graphically compared between the environment and diet. Both amphipod and shrimp prey were smaller in the diet than in the environment. Mean amphipod sizes were generally larger in the environment than in the diet (Figure 3.01). However, in March, April and May, mean amphipod sizes in the diet was larger than in the environment. Mean shrimp sizes in the environment were always larger than mean shrimp sizes in the diet (Figure 3.02). In the diet, the largest mean shrimp size occurred in July. Small postlarval caridean shrimp were eaten in April and May. All shrimp in the diets were small, and mean shrimp sizes in the diet in June and July were approximately the size of postlarval penaeid shrimp.

Overall, the mean size of prey eaten by pinfish in the natural seagrass habitat was approximately 10-12 % of the size of predators and ranged from 2-23 % (Figure 3.03). The size of individual prey ranged from 2 % (smallest) to 35 % (largest) of the predator. Variability in prey size (expressed as a percentage) appeared to increase for larger predators examined. The majority of these prey were peracarids belonging to the amphipod and tanaid groups. Larger prey were caridean or penaeid shrimp. There is no strong variation in the percent of fish size eaten, however, as fish size changes.

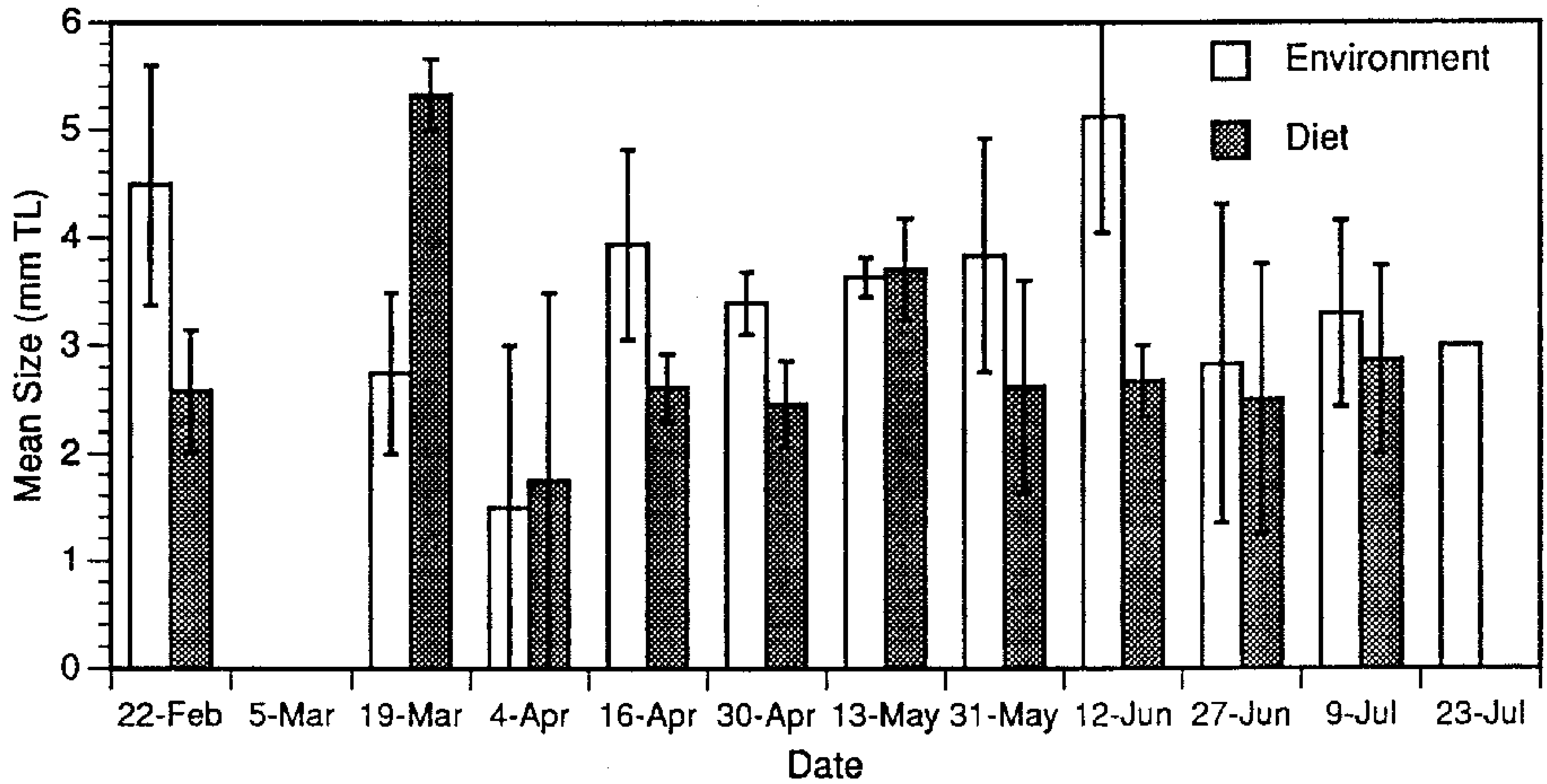

Figure 3.01. Mean size and standard error of amphipod prey from the environment and the stomachs of pinfish during the sampling period.

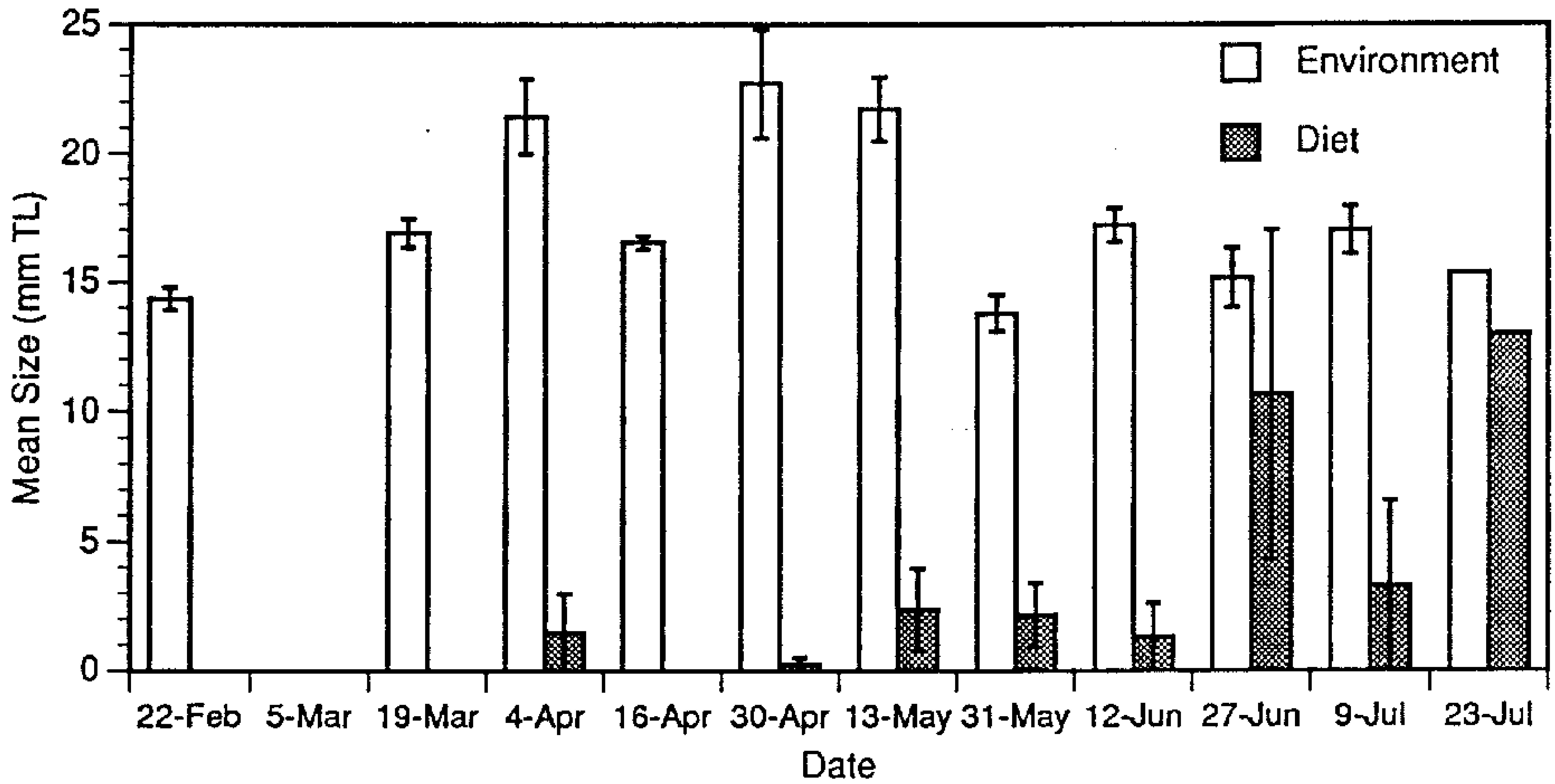

Figure 3.02. Mean size and standard error of shrimp prey from the environment and the stomachs of pinfish during the sampling period.

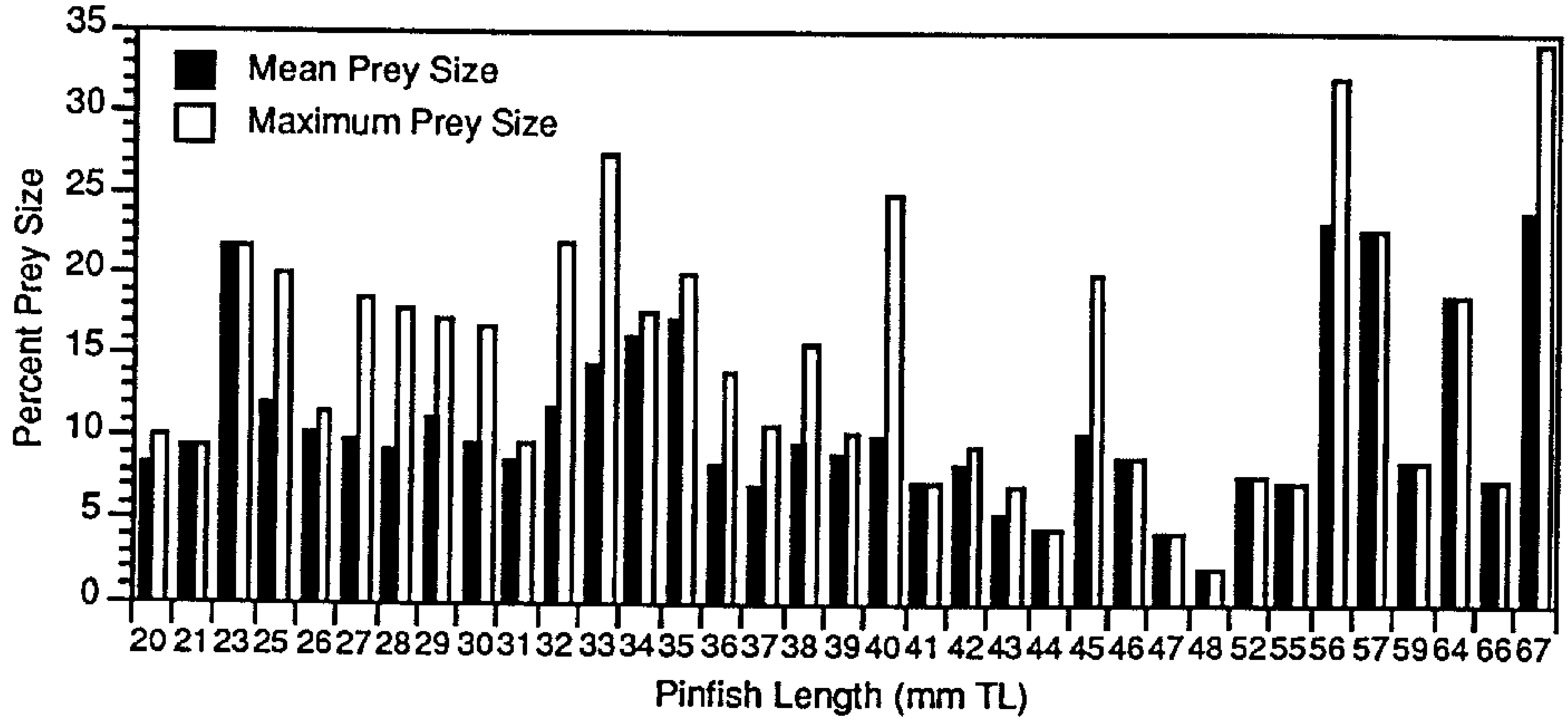

Figure 3.03. Percent prey size compared to total length of pinfish expressed as a mean and the maximum for all measured crustaceans and fish eaten from fish collected in Christmas Bay during the spring 1986.

The one southern flounder (34 mm TL) collected during the spring 1986 had fish in its stomach ranging from 29 to 44 % of its own body length. The southern flounder collected in spring 1985 and analyzed for stomach contents had eaten brown shrimp ranging from 32 to 48 % of their body length (Table 3.02).

Table 3.02. Percent of prey size to fish size for prey from southern flounder collected in Christmas Bay during the spring.

Date	Southern flounder Size (mm TL)	Prey Species	Prey Size	Percent of Fish Size
Spring 1986	34	pinfish	10	29.4
		pinfish	12	35.3
		pinfish	13	38.2
		pinfish	15	44.1
Spring 1985	70	brown shrimp	23	32.9
Spring 1985	44	brown shrimp	14	31.8
		brown shrimp	15	34.1
Spring 1985	42	brown shrimp	20	47.6

Laboratory Experiments

Size Selection In the first series of size-selection experiments, a minimum of twenty replicates were run for each of predator/prey species combinations. However, the number of useable replicates was variable because some fish would not eat within the required three hours or more than one shrimp was eaten before the observation was made. Testing the null hypothesis of all shrimp prey sizes being selected with equal frequency, no significant differences were detected for the pinfish or southern flounder feeding on grass shrimp, or southern flounder feeding on brown shrimp (Table 3.03). In the experiment with pinfish feeding on three sizes of brown shrimp, the larger sizes were significantly selected.

Table 3.03. Size selection by pinfish and southern flounder feeding on grass shrimp and brown shrimp in three relative size categories. Significant values of the calculated χ^2 are indicated by bold, italic type.

Treatment	Size Category			Total	χ^2 Value	Probability
	Small	Medium	Large			
Pinfish						
Grass shrimp	6	10	12	28	3.097	0.223
Brown shrimp	1	6	7	14	***7.733***	0.036
Southern flounder						
Grass shrimp	8	8	3	19	4.261	0.139
Brown shrimp	3	3	6	12	2.201	0.325

In the second size-selection experiment, sixteen pinfish (57-78 mm TL) were examined, and they ate a total of 89 grass shrimp. Prey represented as percent of pinfish size ranged from 18 to 51 %. The maximum number of grass shrimp eaten per pinfish was 8, and mean number of grass shrimp eaten was 5.6. Of the 15 shrimp sizes available, all sizes of prey were eaten (Figure 3.04). There appeared to be low numbers of the largest prey eaten ($\geq$ 27 mm), but the χ^2 value comparing frequency of sizes available with those eaten was not significant at the 5 % level. The smaller pinfish did not eat any shrimp from the 3 largest size categories. Therefore, I divided the 16 predators into two equal groups of relatively small fish

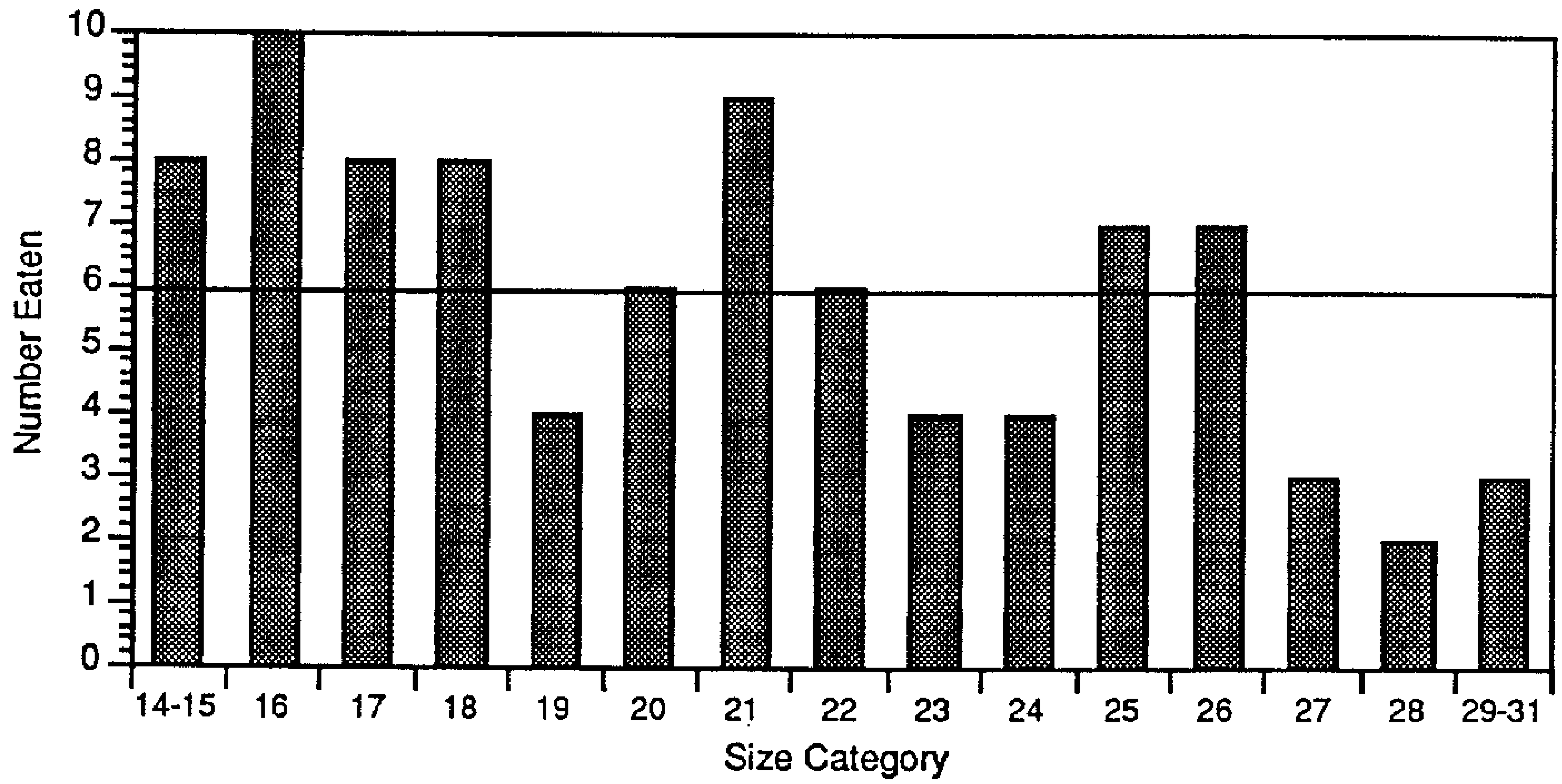

Figure 3.04. Size selection by pinfish feeding on a wide range of grass shrimp prey sizes. Prey size categories available are compared to number within that category eaten. The line represents the expected number eaten if fish had fed evenly on each prey size.

(57-69 mm TL) and large fish (70-78 mm TL). There was still no significant difference in selection in these groups at the 5 % level.

The sixteen southern flounder (76-125 mm TL) were larger than the pinfish examined. Prey represented as percent of southern flounder size ranged from 13 to 37 %. The maximum number of shrimp eaten per southern flounder was 6 and the mean was 2.44. No shrimp were eaten from the 24 mm TL size category (Figure 3.05). However, no trend is evident with some small, medium and large sizes all being eaten more than the expected frequency.

The relationship between predator size and size of prey eaten in the laboratory was also examined using correlation analysis. No significant correlation between fish size and prey size was detected for either pinfish ($r=-0.09$, $n=89$, $p=0.75$) or southern flounder ($r=0.33$, $n=39$, $p=0.20$).

Species Selection Prey species selection experiments indicated a trend for both predators to select brown shrimp over grass shrimp, but no significant differences were detected using the χ^2 statistic (Table 3.04). In the experiment with southern flounder, the addition of amphipods caused a significant χ^2 value which indicated a negative selection for these small prey. Removal of the amphipod data from the contingency table resulted in no significant selection for either shrimp species.

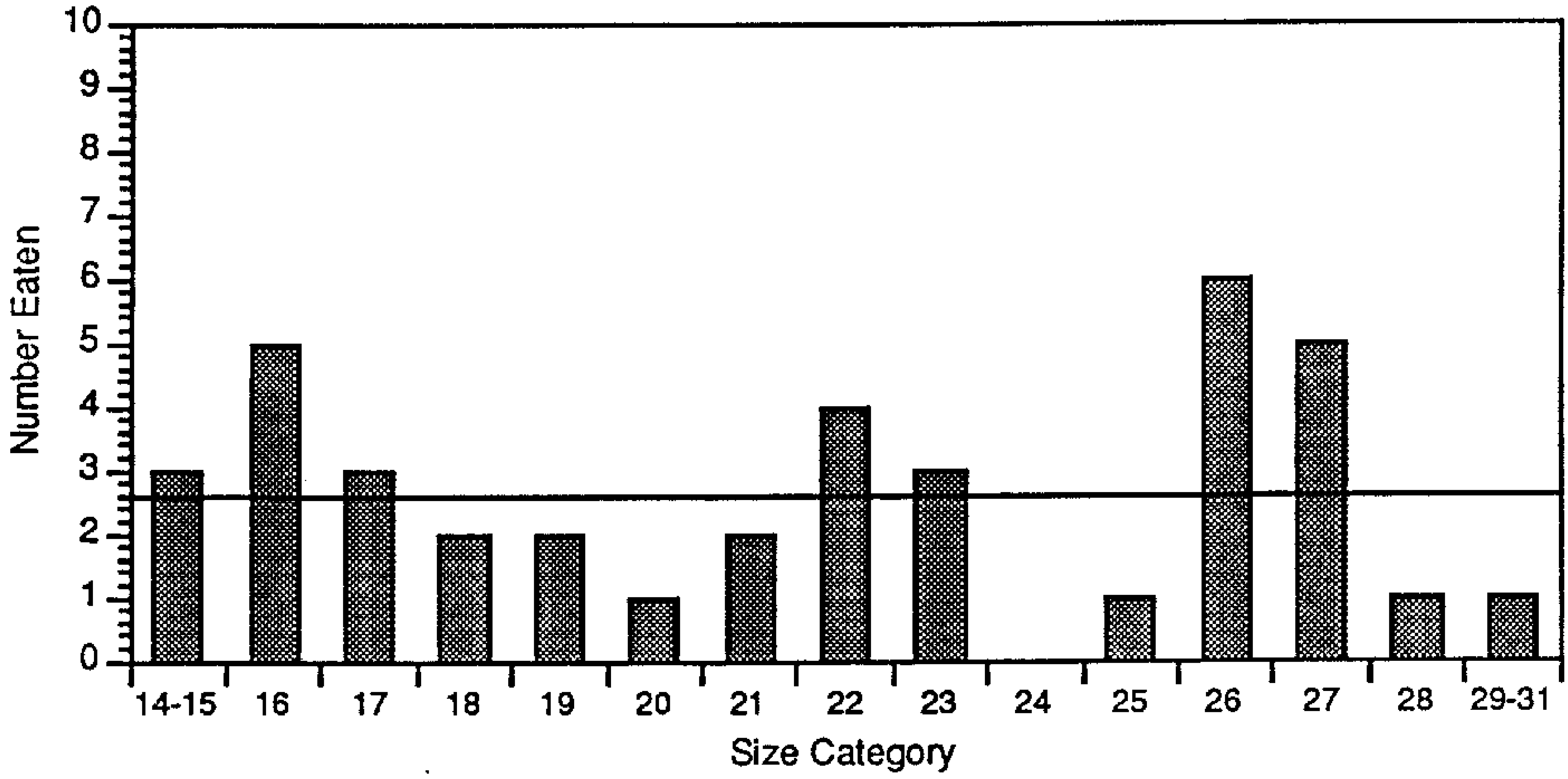

Figure 3.05. Size selection by southern flounder feeding on a wide range of grass shrimp prey sizes. Prey size categories available are compared to number within that category eaten. The line represents the expected number eaten if fish had fed evenly.

Table 3.04. Summary of prey species selection experiments by pinfish and southern flounder. The number of each prey eaten is shown with the mean size of these prey. The experiment on southern flounder is shown with amphipods included and excluded. Significant values of the calculated χ^2 are indicated by bold, italic type.

Predator	**Prey Category**						**χ2 Value**	**Probability**
	A. abdita		*P. aztecus*		*P. pugio*			
	No.	Size	No.	Size	No.	Size		
Pinfish			5	16.8	3	16.3	1.011	0.317
Southern flounder	0	4.4	5	21.1	3	21.3	***7.125***	0.028
without amphipods			5	21.1	3	21.3	1.011	0.317

DISCUSSION

The size of prey occurring in the fish collected in the seagrass bed indicates southern flounder generally consume larger prey than pinfish. Prey of southern flounder were usually 30 to 45 % of the size of the southern flounder compared to prey of pinfish which were 10 to 30 % of the size of the pinfish. Prey type affects the mean size eaten, however, and pinfish diets were dominated by small peracarids in contrast to the larger shrimp and fish present in the diets of southern flounder. Southern flounder, feeding on larger prey, also had fewer prey items in their stomachs. Pinfish ate many small prey which reduced the mean size of prey eaten, but this predator also consumed small numbers of large prey. In fact some prey sizes measured from the field were over thirty percent of the length of the pinfish. Pinfish have been reported to consume some prey types equal to their own size (Main 1985).

Size selection experiments indicated that both predatory fish exhibited no strong size selection among sizes of grass shrimp prey available. However, a trend toward smaller prey was evident when all the data were considered. In contrast, pinfish significantly selected larger brown shrimp. Pinfish ate shrimp up to 51.7 % of their own length. Other size selection experiments have concluded that larger prey are preferred over smaller prey for amphipods (Nelson 1979) and caridean shrimp (Main 1985).

Pinfish and southern flounder did not significantly select either of the shrimp species available. However, a trend towards preferring brown shrimp was evident for both predators. The low number of replicates reduced the power of these tests, and this low power may have resulted in the inability to detect significant differences. In other laboratory selection experiments, pinfish have indicated no preference for different caridean shrimp species (Main 1985). Luczkovich (1989) concluded that prey activity and size were more important factors in selection by pinfish than prey identity.

CHAPTER IV

PREY SELECTION BY PINFISH AND SOUTHERN FLOUNDER IN A NATURAL SEAGRASS MEADOW WITH ENHANCED PREY DENSITIES.

INTRODUCTION

In predation experiments conducted in the laboratory, conditions can be controlled and individual factors manipulated to test specific hypotheses. However, these experiments may not represent natural situations. In dietary analyses of fish predators collected in their environment, prey densities are not controlled, and even when these densities are estimated, they may not represent prey densities at the time of feeding. In addition, information on the hunger level of the predators is unobtainable. Field experiments can be conducted to control both prey densities and hunger level of predators.

Predation experiments conducted in the field have principally used cage enclosures, and two types of studies have been conducted to determine predator effects on prey densities. The first excludes predators from cages and compares prey densities between caged and noncaged natural sites. However, cage effects may be responsible for the observed results rather than the absence of predators (Hurlberg and Oliver 1980). Stocker (1986) initially found non-significant differences in ascidian densities between caged and noncaged sites, but later found significantly greater recruitment at noncaged sites. The second type of cage study includes one predator and excludes all other predators from enclosures. In this approach, differences in prey densities between treatments are the direct result of the presence or absence of the predator since enclosure effects are constant (Walde and Davies 1984). Using this approach, decapod crustaceans (Leber 1985) and fish (Virnstein 1977) have been shown to reduce infauna and epifauna prey populations. These studies provide insight into ways predators affect prey densities.

This experiment was designed to study the response of fish predators to changes in relative prey density in enclosures and to determine if changes in prey density would affect prey selection by pinfish and southern flounder. Densities of amphipods, grass shrimp and brown shrimp were manipulated in enclosures with predators to examine effects of these prey densities on selection.

MATERIALS AND METHODS

Four 1.48 x 0.57 rectangular, solid wall enclosures (height > 60 cm) with the bottoms removed were set in the seagrass meadow and used for three treatments and a control. The control simply enclosed natural densities of prey available when the enclosure was set. Each treatment consisted of adding one hundred individuals of a particular prey: amphipods, grass shrimp (*Palaemonetes pugio*) or postlarval brown shrimp (*Penaeus aztecus*). These experiments were conducted twice using both pinfish and southern flounder as predators within a five week period in the Spring of 1989.

Shrimp prey to be added to experimental containers were collected with 0.5 mm^2 mesh dip nets from the seagrass meadow the morning of the experiment. Only shrimp less than 20 mm TL were used in these experiments. Amphipods were collected from cores and algal clumps associated with the seagrass meadow using a sieve. The majority of amphipods used (>80%) were *Gammarus mucronatus*, although some *Cymadusa compta* and *Grandidierrella bonnieroides* were also used. All prey were sorted, counted and retained in buckets until they were added to the fiberglass enclosures.

Pinfish used as predators were collected from the local Christmas Bay seagrass meadow, while southern flounder were caught in Carancahua Bayou of West Bay. All experimental fish were collected by trawling for no longer than 5 minutes, 24 to 36 hours before the experiment. Experimental fish were held for 24 h in the seagrass meadow in a cage constructed from a 55 gallon plastic drum with both ends removed. The ends were covered with 264 μm mesh to keep copepods out, and the cage was laid on its side to permit water movement. This holding period acclimated fish to water conditions in the seagrass bed. Fish were starved during this holding period, and stomach content analysis performed on a sample of pinfish held in the cage prior to the experiments showed pinfish had empty stomachs.

Prey species were allowed to acclimate for 20 minutes after they were introduced into the treatment enclosures. Four cores were then removed from within each enclosure to estimate initial infauna, epifauna and seagrass densities. The holes left by the cores were subsequently filled by taking cores from outside the enclosure. These cores replaced infauna and epifauna prey and seagrass structure. Replacement of cores also reduced potential problems in collection of animals following the experiment. The fish were then added and allowed to feed. In the pinfish experiments, 15 fish (>50 mm TL) were added to each treatment and allowed to feed for 2 hours. In the southern flounder experiments, 8 fish were added to each treatment and were allowed to feed for 3 hours. Experiments were repeated for each predator species. At the end of the experimental period, predators and macrofaunal prey were recovered from the enclosures using the recovery method described in Chapter 1. Experimental fish were analyzed for stomach contents using the same methods described in Chapter 2. Amount of foods were standardized among treatments and experiments by calculating dry weight and number of prey eaten per fish.

The number of prey in the diet was compared with environmental densities by contingency table analysis. Dependence between frequency of prey in the environment and in the diet was tested with χ^2. Core and sampler prey frequencies were converted to densities in square meters for comparisons. Because of large differences in prey densities between experiments, each experiment was analyzed separately. A contingency table was constructed for each treatment. In addition, selection was determined with the modified selection index. Only one index could be calculated per treatment, however, because there was only one estimate of available prey densities. Therefore, confidence limits could not be determined for the index.

RESULTS

Pinfish

Experiments using pinfish predators were conducted on 29 April and 31 May 1989. Pinfish recovered from the enclosures greater than 50 mm TL were considered experimental animals; 116 out of an initial 120 fish were recovered. Overall mean ± standard error in length was 58.4 ± 0.59 mm TL and dry weight was 612.8 ± 21.38 mg. There was no significant difference in length or weight of pinfish among the eight treatments ($ANOVA_{length}$: df =7, 108, F= 1.19, P > 0.315; $ANOVA_{weight}$: df = 7, 108, F = 0.96, P > 0.467).

Overall prey densities were higher in the first experiment, ranging from 7205 to 8692 individuals per m^2 total prey among the four treatments (Figure 4.01). Total prey density in the second experiment ranged from 3469 to 5004 individuals/m^2 among the treatments. Annelids were the most abundant prey available, and copepods were second in abundance. Because prey densities were much lower in the second experiment, the replicates were treated individually in the analysis.

The stomach contents of experimental pinfish consisted primarily of plant material, and this component contributed over 4.5 mg/pinfish in all replicates (Figure 4.02). Annelids were second in contribution by dry weight in most of the replicates. Prey added in the experiment (amphipods, brown shrimp and grass shrimp) made up between 0 and 4 % by weight of the pinfish diet in these replicates.

Copepods were the most abundant prey in the stomach contents of pinfish, making up over 85 % of all prey eaten. These relatively small prey, however, did not represent a large portion of the diet by dry weight. The effect of experimental treatments on the number of copepods eaten by pinfish was not examined due to previously mentioned difficulty in assessing the number of copepods available as prey, and copepods were not included in the graphical representation of numerically important dietary components in order to increase resolution for prey of interest (Figure 4.03). Other numerically important prey included the

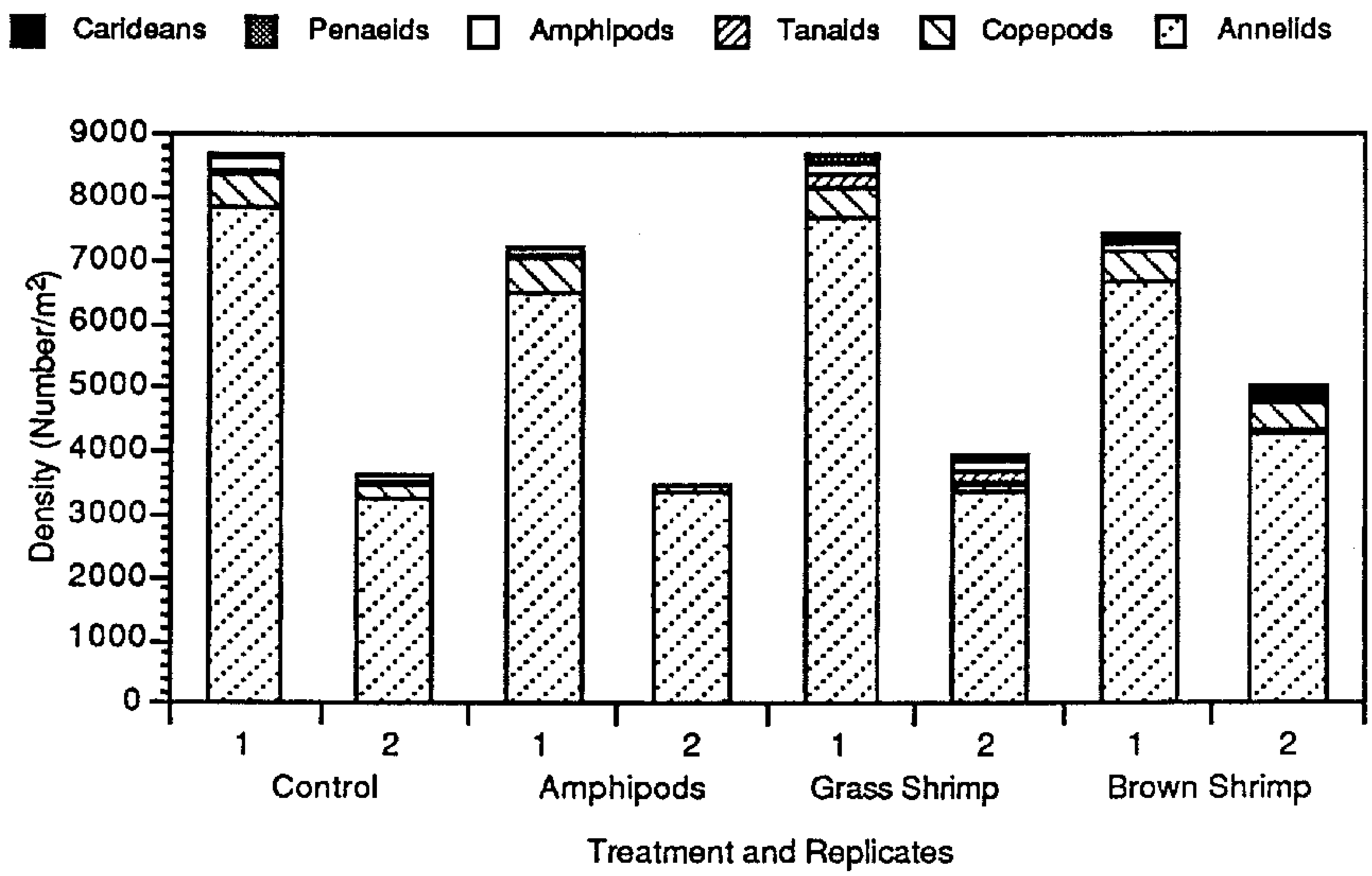

Figure 4.01. Mean density of prey animals available to pinfish in each treatment replicate. Only prey eaten by pinfish were included in the analysis.

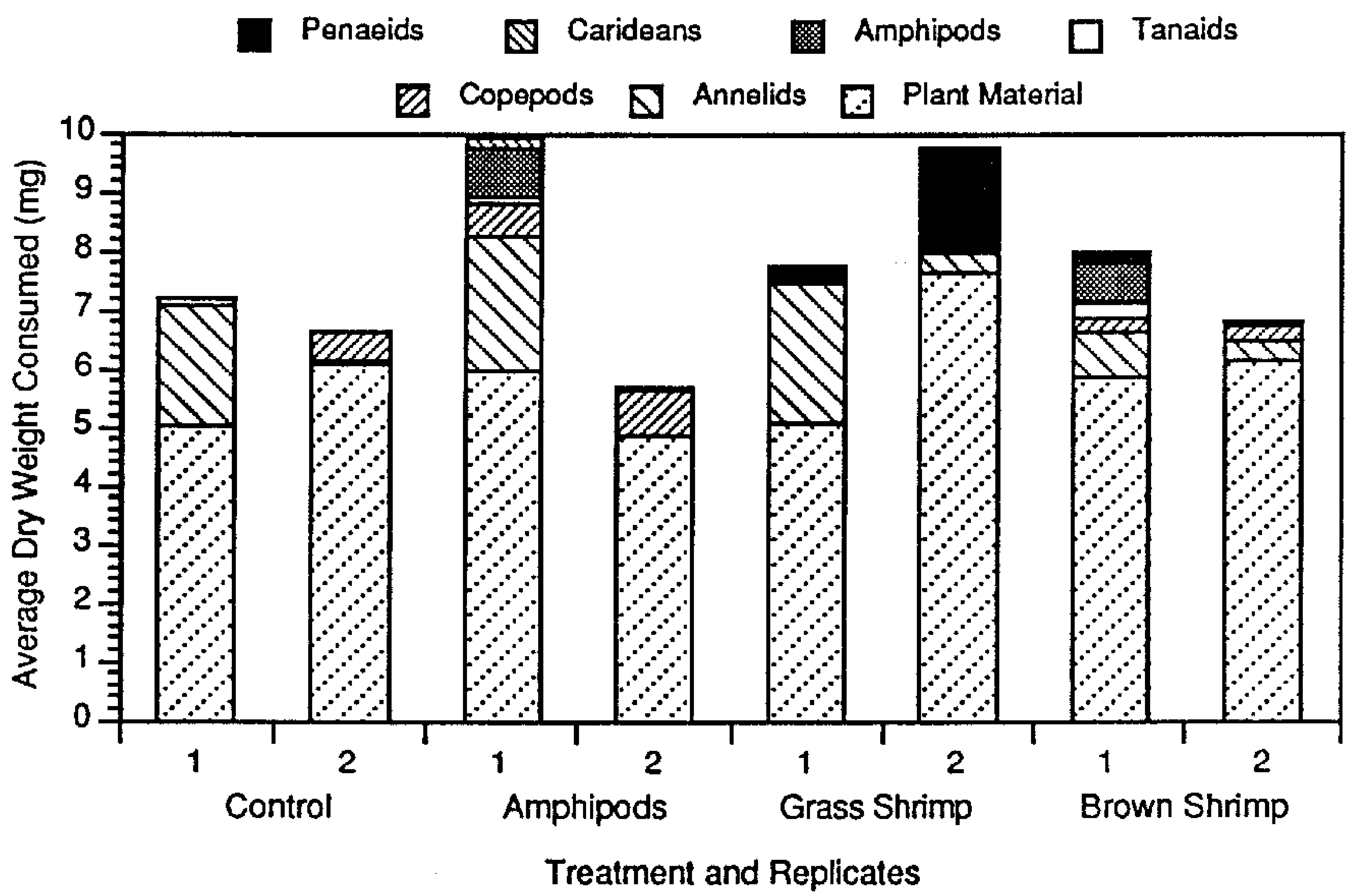

Figure 4.02. Mean dry weight of plant material and prey categories occurring in the stomach contents of pinfish from separate experimental treatments and replicates, as described in text.

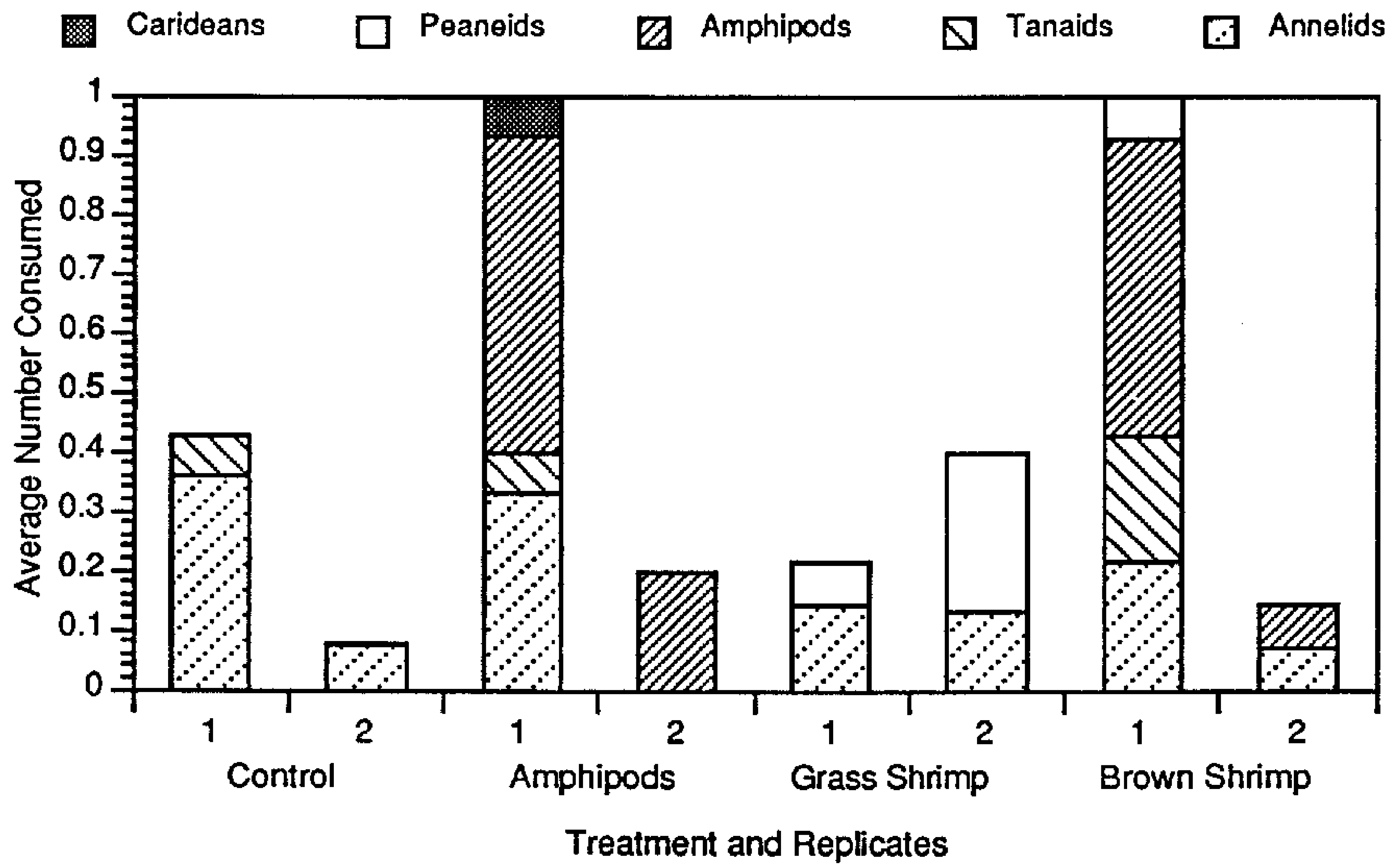

Figure 4.03. Mean number of prey categories (not including copepods) occurring in the stomach contents of pinfish from separate experimental treatments and replicates.

annelids, amphipods and tanaids. Penaeids were less abundant in the diet and caridean shrimp were seldom eaten by pinfish.

The statistical analysis of the experimental effects was limited to effects on prey added in the experiments including amphipods, brown shrimp and grass shrimp. Contingency tables were constructed for each treatment replicate to check for independence between the number of prey available and the number eaten. Controls were not analyzed in these tables because no amphipods, brown shrimp or grass shrimp were eaten by these pinfish. Significant differences between frequency of available prey in the environment and diet were found in the Grass Shrimp treatment of the first experiment (Table 4.01) and Amphipod and Brown Shrimp treatments in the second experiment (Table 4.02). Grass shrimp were not eaten in either of the experiments. In amphipod treatments of the second experiment, the significant selection for amphipods was due to an estimate of available amphipods of zero from the cores. This result suggests some unknown problem with these data because amphipods were added to this treatment and should have been sampled. Caution is advised regarding the power of these tests since frequencies in the diet are low.

Table 4.01. Contingency table analysis summarizing relationships between enhanced prey eaten and available for different treatments in the first pinfish experiment. Shaded area indicates values not used in the analysis. Significant differences from independence are indicated by p values in italics.

Prey Item	Amphipod Environ	Amphipod Diet	Brown Shrimp Environ	Brown Shrimp Diet	Grass Shrimp Environ	Grass Shrimp Diet
Amphipods	96	7	223	0	96	7
Brown Shrimp	39	0	161	1	48	1
Grass Shrimp	0	0	5	0	123	0
Total Chi-square		2.788		1.411		9.326
df, p	1,	0.0950	2,	0.4939	2,	*0.0094*

Table 4.02. Contingency table analysis summarizing relationships between enhanced prey eaten and available for different treatments in the second pinfish experiment. Shaded area indicates values not used in the analysis. Significant differences from independence indicated by p values in italics.

Prey Item	Amphipod Environ	Amphipod Diet	Brown Shrimp Environ	Brown Shrimp Diet	Grass Shrimp Environ	Grass Shrimp Diet
Amphipods	0	3	159	0	64	1
Brown Shrimp	6	0	85	4	10	0
Grass Shrimp	24	0	50	0	152	0
Total Chi-square		33		9.521		2.503
df, p	1,	*0.0001*	2,	*0.0086*	2,	0.2860

Pinfish in the controls did not eat treatment prey in these experiments. This makes it impossible to examine prey selection under unmodified conditions of prey density. However, since only one prey item is manipulated in each treatment, prey densities which were not enhanced should reflect natural, i.e., control densities. According to the modified linear index , amphipods were selected in the Amphipod and Grass Shrimp treatments, and brown shrimp were selected in the Brown Shrimp treatment (Figure 4.04). The same pattern persisted in the second experiment (Figure 4.05). Grass shrimp were avoided in all treatments. When the density of grass shrimp was increased, the negative selection of grass shrimp tended to decrease.

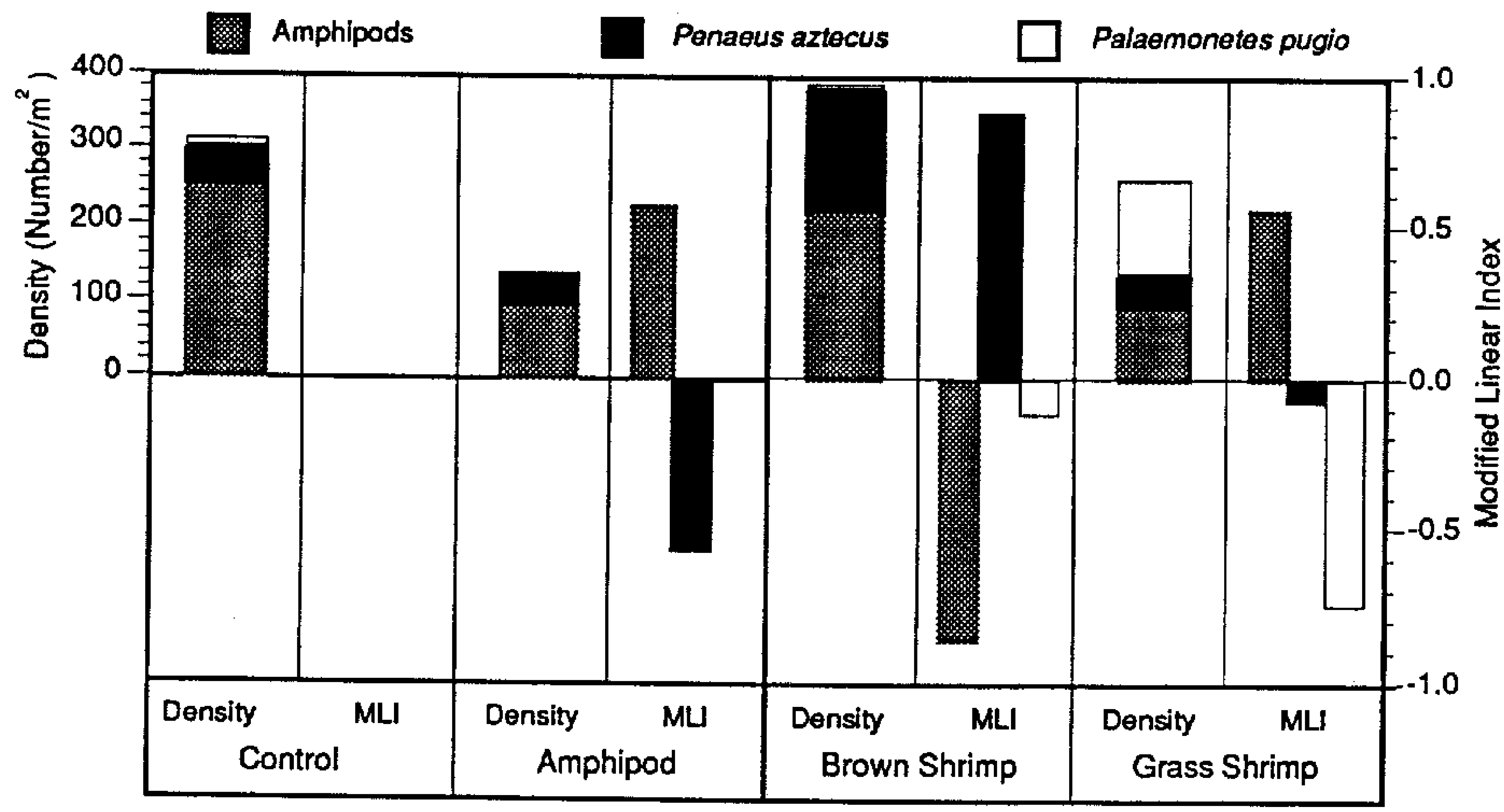

Figure 4.04. Density and Modified Linear Index of treatment prey items for each treatment in the first experimental replicate with pinfish.

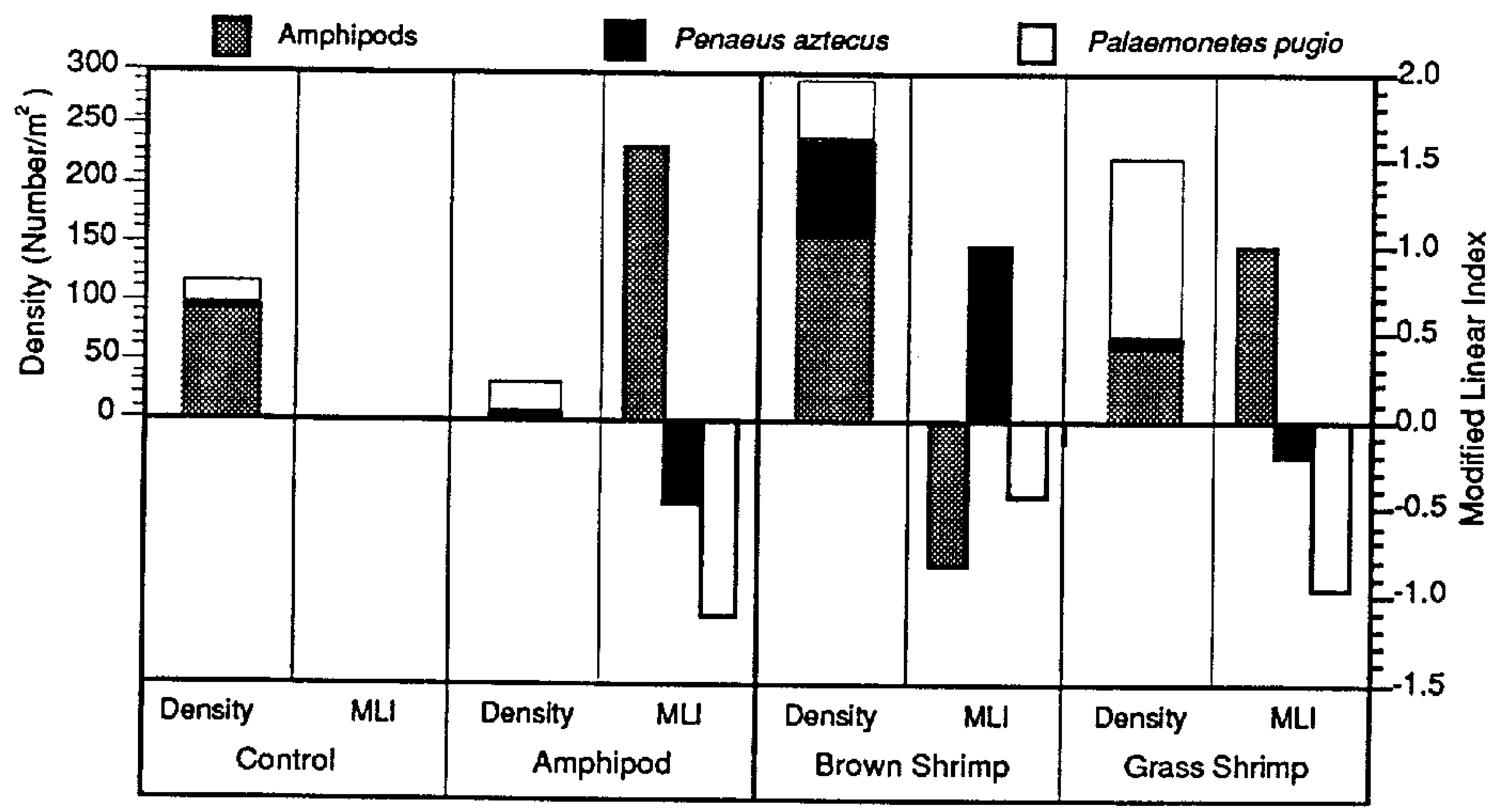

Figure 4.05. Density and Modified Linear Index of treatment prey items for each treatment in the second experimental replicate with pinfish.

Southern flounder

Southern flounder experiments were conducted on 6 May and 1 June 1989. All 64 southern flounder added to the enclosures were recovered after the experiments were completed. Overall mean ± one standard error in length was 76.9 ± 1.75 mm TL and dry weight weight was 856.6 ± 66.3 mg. There was no significant difference in length or dry weight of southern flounder among the 8 experimental treatments ($ANOVA_{length}$: df =7, 56, F= 1.28, P > 0.275; $ANOVA_{weight}$: df = 7, 56, F = 1.09, P > 0.384).

Although southern flounder were starved for more than twenty-four hours, most did not eat during the experimental period. In the first experiment, only 5 of the 32 southern flounder consumed prey; all prey were small fish (silversides and pinfish). No further analysis was completed because no treatment prey were consumed in this experiment. In the second experiment, 8 of the 32 southern flounder had prey in their stomachs. However, none of the southern flounder ate in the Grass Shrimp treatment.

Densities of the available prey were apparently variable among the four treatments of the second experiment even before prey additions. The control had the lowest number of prey items and did not have any grass shrimp present. Treatment prey additions, however, were reflected in prey densities (Figure 4.06); amphipods, brown shrimp and grass shrimp densities were largest in the respective treatments in which they were introduced. The density of the silverside, *Menidia* sp., was similar among the control and treatments; it was highest in the Grass Shrimp treatment.

Shrimp and silversides were the only prey items consumed by southern flounder (Figure 4.07). Fish contributed 13.5 mg/southern flounder in the Brown Shrimp treatment and 22.5 mg/southern flounder in the Control. Contributions in dry weight by shrimp were much lower. Brown shrimp ranged from 1.3 to 5.8 mg/southern flounder, and the brown shrimp contribution was highest in the Amphipod treatment. Grass shrimp were only eaten in the

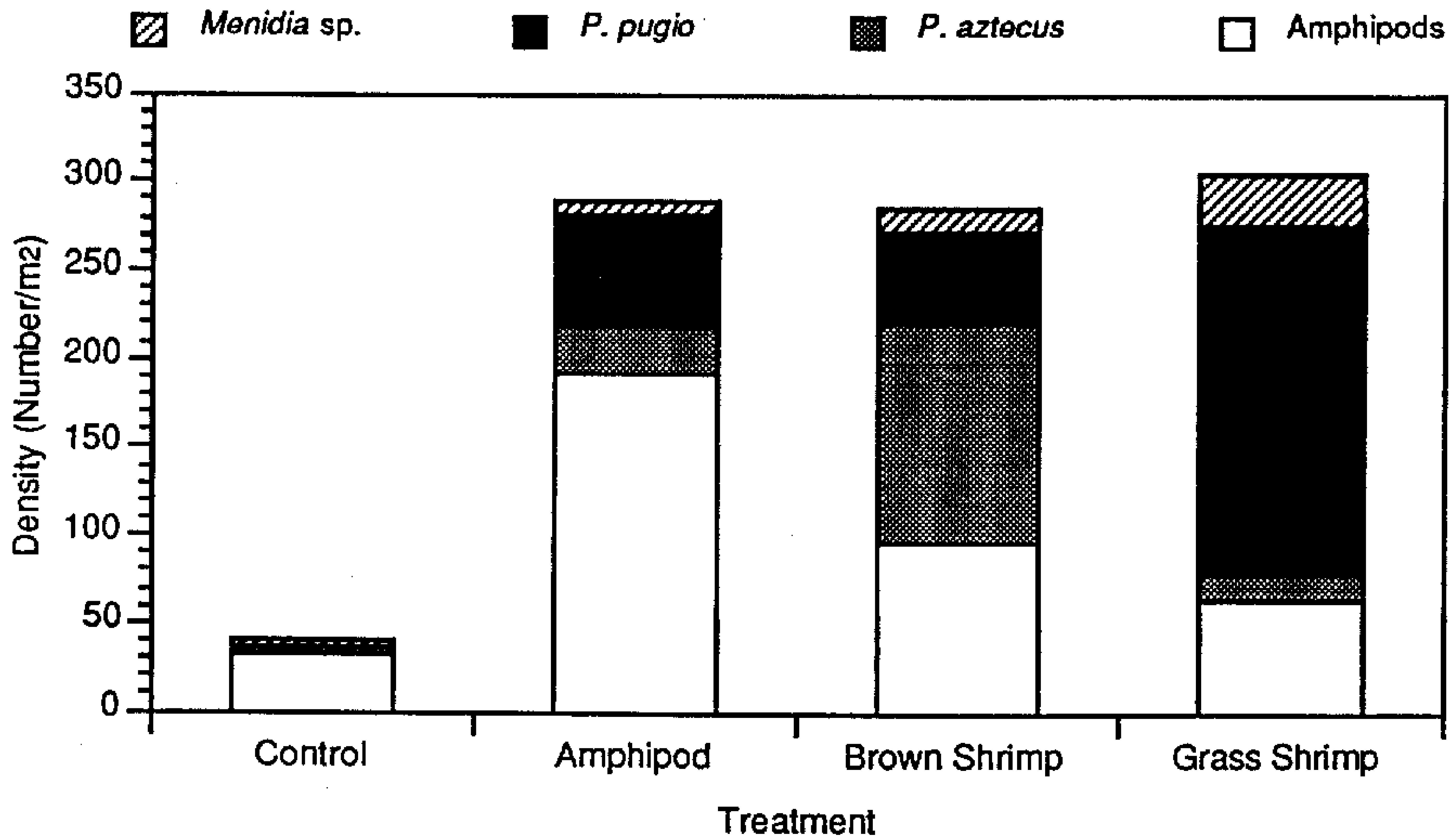

Figure 4.06. Mean density of prey animals eaten by southern flounder in each treatment from the second replicate.

Brown Shrimp treatment and made up 0.5 mg/southern flounder of the dry weight. When examined by number, brown shrimp contributed the greatest portion of food in the diet of southern flounder (Figure 4.08).

In the contingency table analysis, significant differences between frequencies in the environment and diet occurred in the Control and Brown Shrimp treatments (Table 4.03). However, caution is advised on the reliability of these tests because of low frequency numbers in the diet of southern flounder. Comparisons of selection among treatment prey using the modified linear index revealed brown shrimp were selected in all treatments by southern flounder (Figure 4.09). Brown shrimp had a large positive MLI even when densities of these prey were low, suggesting that brown shrimp are a preferred food of southern flounder. The MLI for grass shrimp was near zero or negative in the two treatments where grass shrimp were available. For amphipods, the MLI was always negative, reflecting the absence of any amphipods in fish stomachs despite their relatively large numbers in the environment.

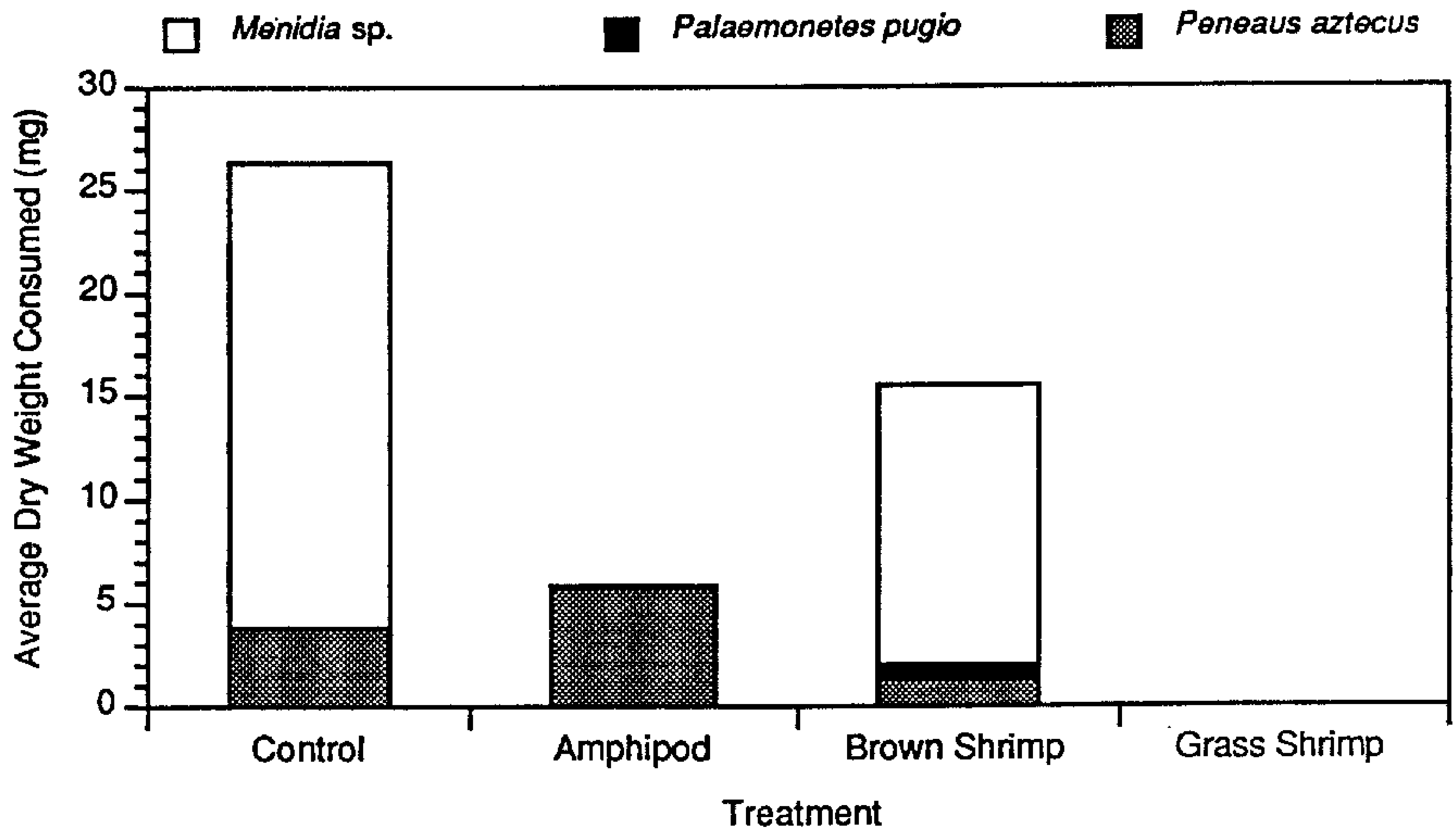

Figure 4.07. Mean dry weight of prey occurring in the stomach contents of southern flounder from separate experimental treatments in the second experiment.

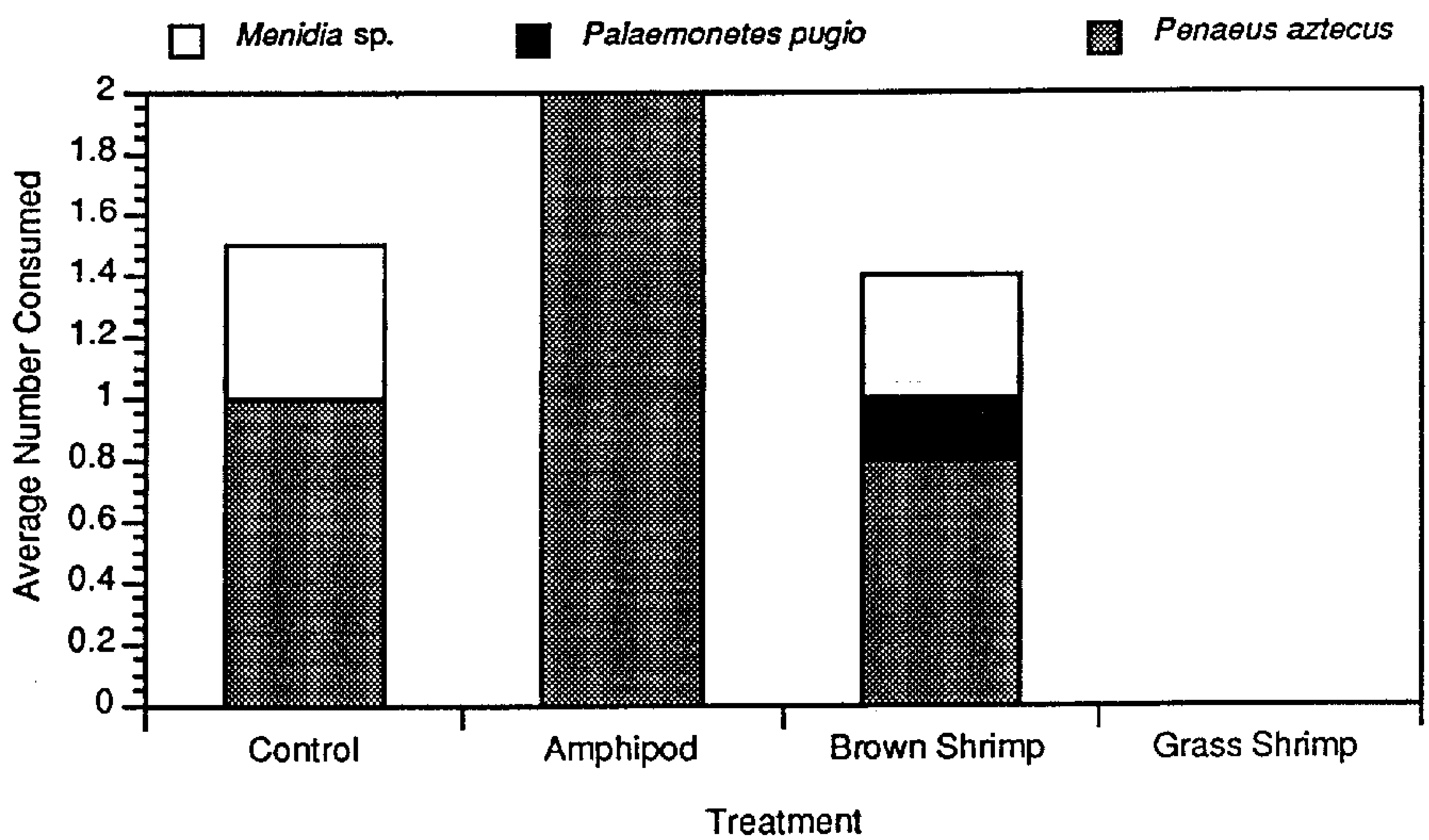

Figure 4.08. Mean total number of prey occurring in the stomach contents of southern flounder from separate experimental treatments in the second replicate.

Table 4.03. Contingency table analysis summarized for treatment prey items in the second southern flounder experiment. Shaded area indicates values not used in the analysis. Significant differences from independence indicated by p values in italics.

	Control		**Amphipod**		**Brown Shrimp**	
Prey Item	Environ	Diet	Environ	Diet	Environ	Diet
Amphipods	32	0	191	0	96	0
Brown Shrimp	5	2	27	1	126	4
Grass Shrimp	0	0	62	0	49	1
Total Chi-square		2.788		1.411		9.326
df, p	1,	*0.0019*	2,	0.4939	2,	*0.0094*

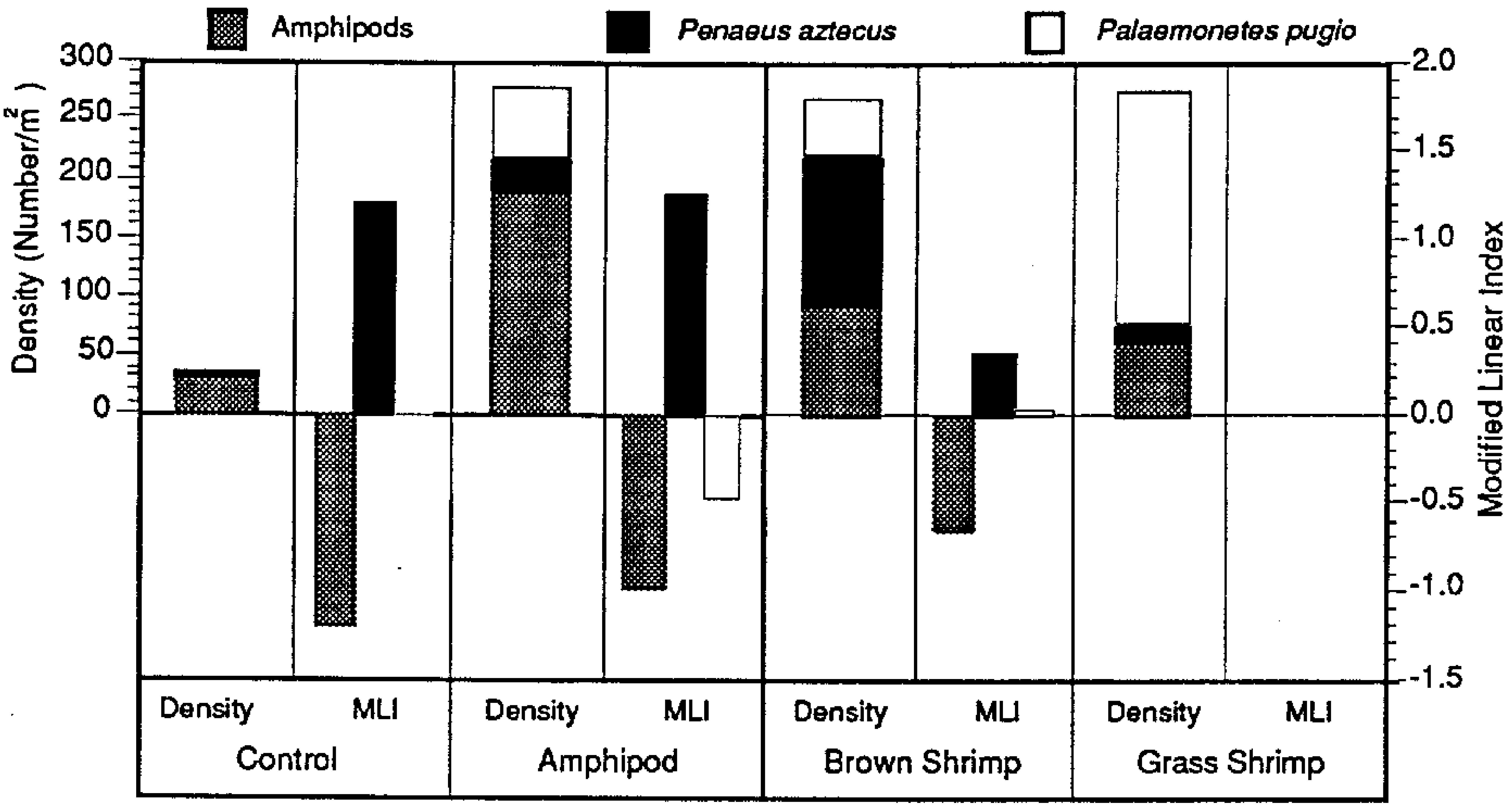

Figure 4.09. Density and Modified Linear Index of treatment prey items for each treatment in the second experimental replicate with southern flounder.

DISCUSSION

The effects of changes in prey density on prey selection of fish cannot be adequately studied in typical analyses of field-collected predators. Even when accurate estimates of prey densities are available, many factors are typically correlated with prey density. Among others, these factors include temperature, salinity, vegetative cover, other prey densities, and predator densities. Time and location of predator and prey collection also affect these correlations. Field experiments reduce these problems by manipulating prey density without varying levels of other environmental factors.

The low frequency of treatment prey occurring in the diet of experimental fish was unexpected. Of the 116 experimental pinfish, only 19 had eaten amphipods, brown shrimp or grass shrimp. Only 13 of the 64 experimental southern flounder had eaten, and only 6 of these ate treatment prey. The low feeding frequency may be related to the short duration of the experiment. However, this short period was required because many prey are unidentifiable after 3-4 hours in the stomachs of these fish following ingestion. If the experiments were allowed to progress for a longer period of time, initial prey eaten may have been missed in the stomach contents.

Despite the limited data, pinfish generally selected amphipods over grass shrimp and brown shrimp among the treatment prey, except when brown shrimp were present in elevated densities (Brown Shrimp treatment). In contrast, brown shrimp were only selected for in the Brown Shrimp treatment. These results suggest a certain threshold density may be required before pinfish selectively feed on brown shrimp. Grass shrimp were avoided in all treatments, even when their densities had been increased.

In southern flounder experiments, relatively few prey were eaten. However, southern flounder selected brown shrimp over amphipods and grass shrimp. Amphipods and grass shrimp were not selected even in treatments where their densities were enhanced.

CONCLUSIONS

The drop sampler with rotenone technique was an efficient method providing a quantitative measure of small macrofauna densities in the Christmas Bay seagrass meadow. Rotenone caused burrowed animals to leave the sediments which resulted in high density estimates. This sampling effort should provide some of the best estimates available of macrocrustacean and small fish densities. The datasonde was also a unique tool in this study; it provided continuous measurements of temperature, salinity and dissolved oxygen. The datasonde record permitted a more elaborate analysis of changing environmental patterns than recordings made within each sampler.

The Christmas Bay seagrass meadow is a dynamic habitat during the spring and early summer. Infauna and epifauna species within the *Halodule wrightii* seagrass meadow had variable densities, and densities peaked in April and May during the spring and early summer of 1986. Low infauna and epifauna densities in the early spring were the result of mortalities caused by environmental extremes. These environmental extremes were caused by cold fronts passing through the area which reduced temperatures and salinities, and exposed large portions of the seagrass meadow. Declines in animal densities after May were attributed to predation. Despite declining densities over the sampling period, pinfish were one of the most abundant predators of infauna and epifauna present in the seagrass bed.

The Strauss linear index, originally calculated to examine prey selection, was not distributed normally, and variances among sampling dates were heterogeneous. A modified linear index (MLI) was calculated with arcsine-transformed data, and this modified index generally met the assumption of normality needed to allow testing for selection. Confidence limits provided a means of testing whether the MLIs were significantly different from zero (random feeding).

A shift from carnivory to herbivory was observed in pinfish diets as the fish grew through the spring and early summer. Previous studies have suggested that this shift represents a true switch with size in dietary preferences. In my study, however, this shift in pinfish diets for predominantly animal foods to plant foods corresponded to a decrease in available animal prey. An examination of predator size-related diets of pinfish from high prey density periods and low prey density periods suggests that prey density may be more important than predator size. The ingestion of plant material by larger pinfish during periods of low prey density may be incidental and related to a requirement for repeated attacks on the few prey available during these periods.

Within animal prey, copepods appeared to be strongly selected. Sampling for these prey, however, may have been inadequate making this result unreliable. Among other prey commonly eaten, annelids were generally selected against for most sampling dates. In contrast, amphipods were positively selected through the sampling period. As size of the pinfish increased penaeid and caridean shrimp were eaten more frequently. Although a tendency of positive selection occurred for shrimp prey, feeding was not significantly different from random.

The density of juvenile southern flounder in Christmas Bay was low. Field-collected southern flounder consumed annelids, shrimp and fish. Although shrimp were more frequent in the diet of southern flounder, fish contribute a larger portion to the diet in terms of dry weight.

The prey eaten by pinfish collected in Christmas Bay ranged from 10 to 33 % of the total length of pinfish. In laboratory size-selection experiments, pinfish did not select a particular size of grass shrimp when prey were less than 50 % of the total fish length. However, a tendency for selection of larger brown shrimp was indicated. Southern flounder did not select any particular size of prey when prey were less than 50 % of their total length in laboratory experiments. Southern flounder and pinfish select brown shrimp over grass shrimp prey in the laboratory, but not significantly.

In field experiments where prey densities were manipulated, pinfish selected amphipods as prey except in treatments where brown shrimp postlarvae were added. Pinfish appeared to switch their preference to brown shrimp when brown shrimp were present in high densities. Grass shrimp were negatively selected by pinfish regardless of prey densities. Southern flounder strongly selected for brown shrimp at low and high prey densities, and generally avoided grass shrimp and to some extent amphipods.

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VITA

Thomas E. Czapla was born in Buffalo, New York, on 14 December 1958. He was the youngest of four sons (Andrew, Howard and John) of John S. and Anne B. Czapla. He graduated from Kenmore East High School in June 1976. He matriculated with a Bachelor of Arts in Biology/Psychology from Canisius College in May 1980 and a Master of Arts in Biology from the State University College of Buffalo New York in May 1983. He entered a doctoral program in biology at Texas A&M University in August 1982.

During his undergraduate and graduate work in Buffalo, he dated and married Ms. Gretchen L. Payne. They are the proud parents of Robin Anne, born 6 March 1990. The family's permanent address is 4830 Houston Drive, Galveston, Texas, 77551.

Among many positions held during his graduate career, he worked mainly at the National Marine Fisheries Service Galveston Laboratory, from October 1985 to the present. Beginning as a biological technician, he has been subsequently promoted through several levels to his present position as an ecologist.